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PROCEDURES MANUAL

DYNAMIC STABILITY ANALYSIS FOR U.S. NAVY SMALL CRAFT

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COMBATANT CRAFT ENGINEERING
NAVAL SHIP ENGINEERING CENTER, NORFOLK DIVISION
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This manual presents the procedures and background information necessary to perform a transverse dynamic stability analysis of U.S. Navy small craft. The manual is intended for use by new engineers and technicians who might not be familiar with the stability aspects of Naval Architecture. The procedure has been ordered and sequenced (and work sheets provided) so that the analysis can be performed, comparison made with stability criteria, and conclusions — 7 over

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drawn with respect to the adequacy of the craft's stability. The step-by-step method presented will expedite the performance of the analysis, reduce the possibility of errors, and provide complete documentation for design reference. Included is a limited amount of theory explaining each signigicant step in the analysis. The intent is to provide the analyst with a basic understanding of transverse stability. A complete treatment of the subject may be found in other publications.

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Prepared for

Combatant Craft Engineering
Naval Ship Engineering Center, Norfolk Division
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by

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PART I - THEORY

1.0 INTRODUCTION

This manual presents the procedures and background information necessary to perform a transverse dynamic stability analysis of U.S. Navy small craft.

The manual is intended for use by new engineers and technicians who might not be familiar with the stability aspects of Naval Architecture. The procedure has been ordered and sequenced (and work sheets provided) so that the analysis can be performed, comparison made with stability criteria, and conclusions drawn with respect to the adequacy of the craft's stability. The step-by-step method presented herein will expedite the performance of the analysis, reduce the possibility of errors, and provide complete documentation for design reference.

Included is a limited amount of theory explaining each significant step in the analysis. The intent is to provide the analyst with a basic understanding of transverse stability. A complete treatment of the subject may be found in "Principles of Naval Architecure" published by the Society of Naval Architects and Marine Engineers and in other standard works.

1.1 DEFINITION

When a craft is tilted by some disturbing influence it tends to return to its upright position or else to overturn. This tendency to rotate one way or another is referred to as its stability. The measure of this stability is

a moment tending to restore or overturn the ship. The moment is made up of two forces: buoyancy and gravity. When the ship is at rest these forces both act in the same vertical line. When the ship is rotated from the at rest position the shape of the buoyant volume changes thereby shifting the center of buoyancy away from its initial line of action through the center of gravity. This displacement of the two equal and opposite forces produces the above mentioned moment.

The disturbances to stability are wave action, wind, high speed turns, recoil from gun fire, rocket blasts, off-center weights and others. An analysis of transverse stability is made to determine the effectiveness of the ship in countering some or all of these disturbances.

The buoyancy characteristics of a particular craft are set forth in the "Curves of Form" and "Cross Curves of Stability". Examples of these are shown in Figures 1 and 4.

1.2 CONDITION OF CRAFT LOADING

Transverse stability varies with the condition of the craft in that the relationship between the two forces, buoyancy and gravity, are varied with change in loading, i.e., the weight of the craft and its distribution. Typical load conditions which are checked against stability criteria are:

(a) Full load condition

(b) Full load plus overload

(c) Minimum operating

(d) Minimum operating plus overload

(e) Light

These load conditions are influenced by craft weight, ammunition, stores, potable water, fuel, cargo, complement, and other items of variable load determined by the requirements of the craft's mission and its condition at departure and return.

NAVSHIPS FORM 4616 A-4 (11-57) "Estimate of Weight for Ships" or NAVSHIPS FORM 4616-2 (REV 11-57) "Estimate of Weight for Boats" (several pages) provides the load conditions with a weight breakdown and other information required for this stability analysis (See Appendix - sample copy of a weight/condition estimate).

1.3 INTACT AND DAMAGE STABILITY

The underwater body may be intact or it may be damaged so that the sea is no longer excluded. Analysis of both conditions must be performed. The procedure is basically the same. Damage results in flooding, however, which causes a change in buoyancy, trim and other factors which must be allowed for in the stability analysis. The changes in buoyancy characteristics of the flooded compartments are set forth in "Damage Stability Calculations". See Figure 18 for sample computer printout of the buoyancy data for a damaged condition.

1.4 OPERATION OF THE CRAFT

Forces which influence the stability of the craft during operation are as follows:

(a) High Speed Turn

(b) Gun fire, rocket blast

(c) Shifting of weights on board

(d) Addition of off-center weights

(e) Collision or enemy hit impact

1.5 ENVIRONMENT

Operating environment influences the stability of the craft and the upsetting forces are from:

(a) Wind - primarily beam

(b) Icing - primarily top side

(c) Wave action

The effect of these items and those in section 1.4 above are included in the stability analysis.

1.6 CRITICAL COMBINATIONS OF FORCES

The transverse stability is examined for a combination of forces acting concurrently, usually beam wind and wave action, but frequently including icing or other factors set forth above. One of the objectives of the analysis is to determine the limitations of the craft or, sometimes, the operational techniques which can be used to minimize the effects of extreme environment.

2.0 HYDROSTATIC CHARACTERISTICS OF THE CRAFT

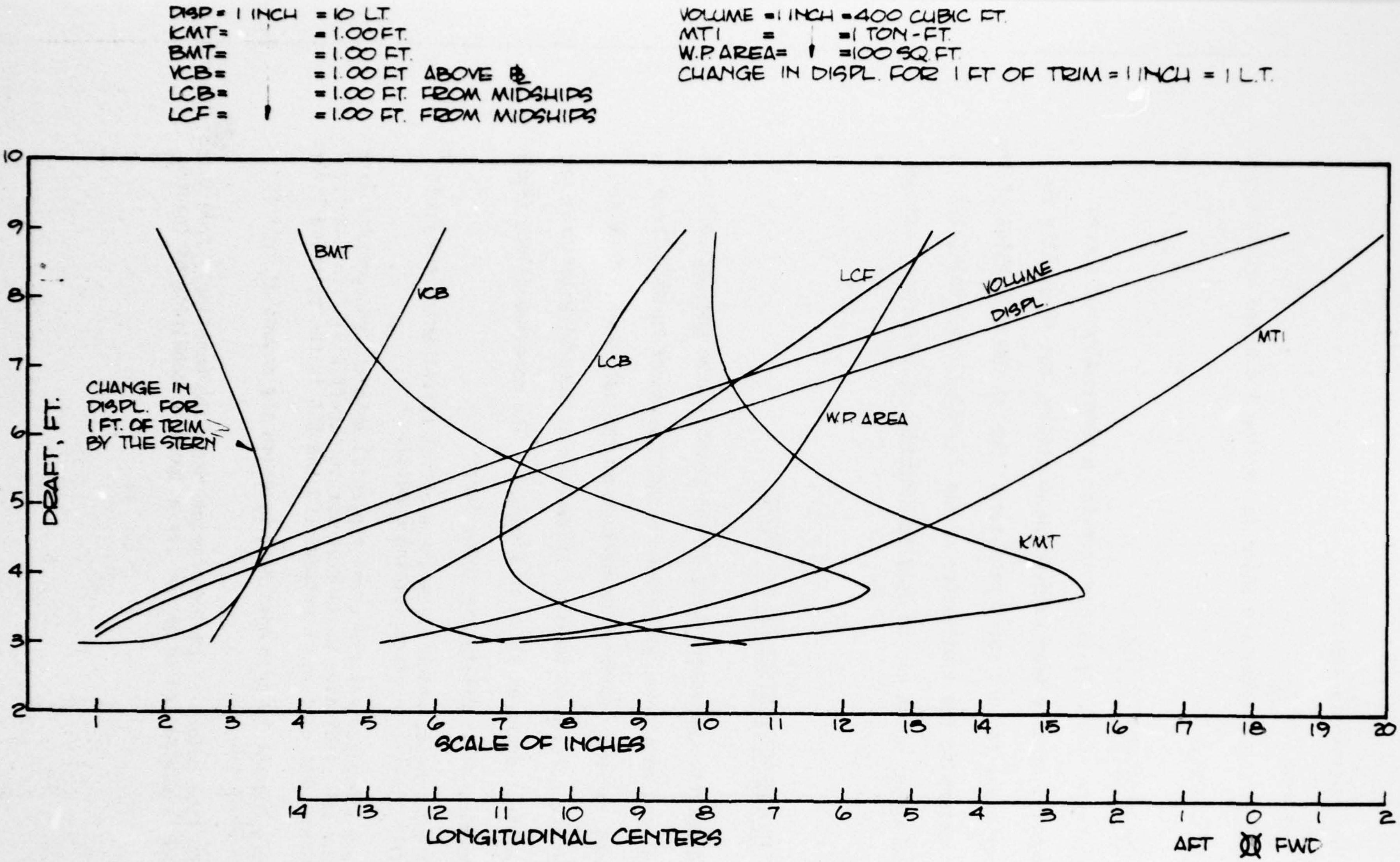
The hydrostatic characteristics of the craft in the upright position, i.e., zero heel and zero trim, are given in the "Curves of Form". These curves represent various geometric properties of the hull form. They are calculated for the portion of the hull below each of several waterlines and then plotted against draft as shown in Figure 1. The more important curves from the standpoint of stability are those for:

(a) Displacement, which gives the draft at LCF at which the craft will float in a given loading condition.

(b) LCB (longitudinal center of buoyancy) which, when compared with the LCG, indicates whether or not the craft will float at level trim. The difference between LCB and LCG is the trimming lever.

(c) MT1 (moment to trim one inch) by which the amount of trim is calculated.

(d) KM (the height of the metacenter above the baseline), from which KG is subtracted to get GM for a specific condition of loading.



CURVES ARE BASED ON 0 TRIM. DO NOT SCALE DRAWING

FIGURE 1
CURVES OF FORM FOR 100' CPIC-X

In general, these calculations are done on the summary weight sheets of the Navships forms mentioned in paragraph 1.2 above.

The hydrostatic characteristics of the craft when inclined to small and large angles are discussed in sections 2.1 and 2.2 following.

2.1 METACENTER AND METACENTRIC HEIGHT

As a craft is rotated, at constant displacement, away from its upright position of equilibrium the centroid of the underwater volume moves off the centerline and upward describing a curve. The center of curvature of this curve is the metacenter. Looked at another way, the metacenter is the intersection of verticals through the center of buoyancy when the craft is rotated, at constant displacement, through an infinitesmally small angle. There is a metacenter for any position of a body which pierces the surface of the water, whether wholly or partially supported by the buoyancy of the immersed volume. Physically the metacenter is the highest point to which the center of gravity may be raised and still retain positive stability, as described in the next paragraph. In general, the metacenter is a useful measure of stability at small angles only. See Figure 2, as discussed below.

If the center of gravity, G, is at the metacenter, M, the craft is neutrally stable. That is, when given a small rotation it will tend to remain in its new position. If G is above M (negative GM) the craft is in unstable equilibrium and, if given a small rotation, will tend to rotate further. Conversely, when G is below M (positive GM), the craft is in stable equilibrium and, when given a small rotation will tend to return to the original position. The greater the GM (assumed positive) the stronger the tendency to remain upright. The distance GM is known as the metacentric height and is a direct measure of initial stability, as just described. However, GM itself does not

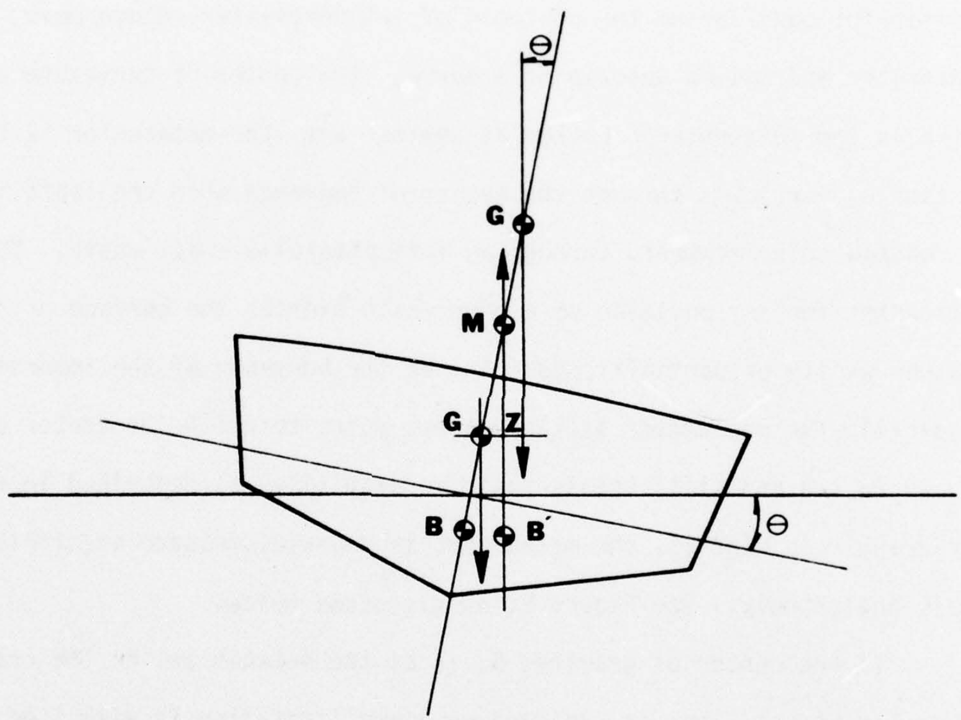


FIGURE 2
POSITIVE, NEGATIVE, AND NEUTRAL STABILITY

right the craft, but the couple formed by the weight and buoyancy of the craft when they are displaced from their co-linear positions.

These features are illustrated in Figure 2 in which the heel angle, θ, is exaggerated for clarity. The distance between the lines of action of buoyancy and gravity is shown in the figure as GZ, the righting arm. The righting moment is equal to the righting arm multiplied by the displacement, Δ, or

$$RM = \Delta \, GZ$$

For small heel angles, up to about 7°, the metacenter is considered to remain fixed on the centerline of the craft. Thus for small angles the righting arm is

$$GZ = GM \sin \theta$$

and the righting moment is therefore

$$RM = \Delta \, GM \sin \theta$$

The stability is directly proportional to GM.

The initial GM is related to the period of roll of the craft by the equation

$$T = \frac{kB}{\sqrt{GM}}$$ where T = natural roll period, sec.

B = maximum beam of the craft, ft

k = constant

The constant, k, accounts for the transverse radius of gyration (a function of beam) and the damping effects. A value of 0.44 is used unless another value has been determined by model or, preferably, full scale tests.

2.2 STABILITY AT LARGE ANGLES

At angles of inclination beyond 8 to 10 degrees the metacenter is no longer significant since the righting arm (and moment) is no longer proportional to the initial GM. The stability of the craft is still, however, dependent on the relationship of the center of buoyancy to the center of

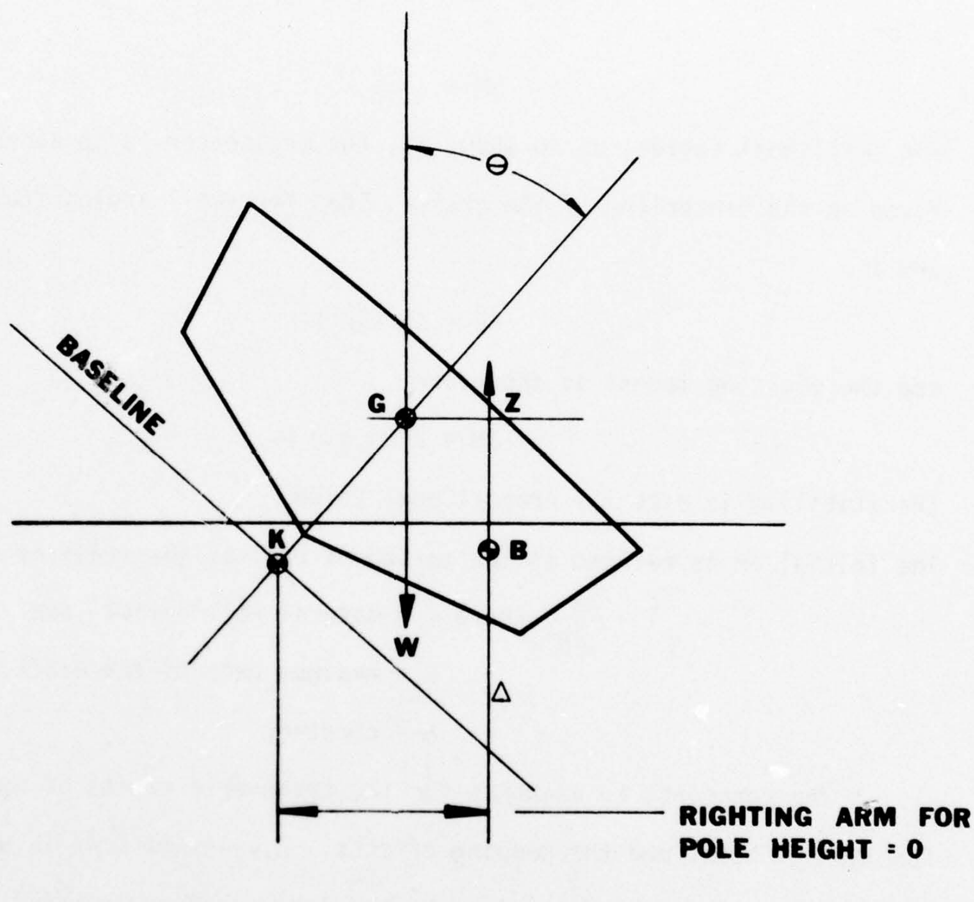


FIGURE 3
STABILITY DEFINITIONS AT LARGE ANGLES

gravity. Referring to Figure 3:

Heel angle = θ

Weight of craft, W, = buoyant force, Δ, = displacement.

GZ = righting arm

Restoring Couple = Δ GZ = Righting Moment, RM.

Calculations of righting arm for pole height = 0 (G assumed at baseline) at several displacements and heel angles are done on a computer and printed out for use in the stability analysis.

2.3 CROSS CURVES OF STABILITY

Righting arms for several displacements at each angle of heel are plotted as shown in Figure 4. They are based on an assumed vertical location of the center of gravity of the craft, considered to be at the base line (pole height equals zero). Righting arms can be corrected for any vertical location of the center of gravity. They are based on the assumption of fixed trim of the craft for all heel angles. This assumption is considered to be valid for trims less than 1% of the waterline length. If greater trim will occur the righting arms must be calculated for one or more additional trim conditions.

2.4 RIGHTING ARM CURVE

Figure 5 shows a curve of GZ plotted against heel angle. This curve must be drawn for a specific loading condition, that is, a specific displacement and vertical center of gravity. The righting arms at a specific displacement are read off the cross curves at each heel angle and corrected for the vertical shift in C.G. as described in 2.5 below. They are then plotted against heel angle as in Figure 5.

The curve shows the following important characteristics of transverse stability and the craft's ability to resist capsizing in a given condition.

ASSUMED C.G. AT - BASELINE

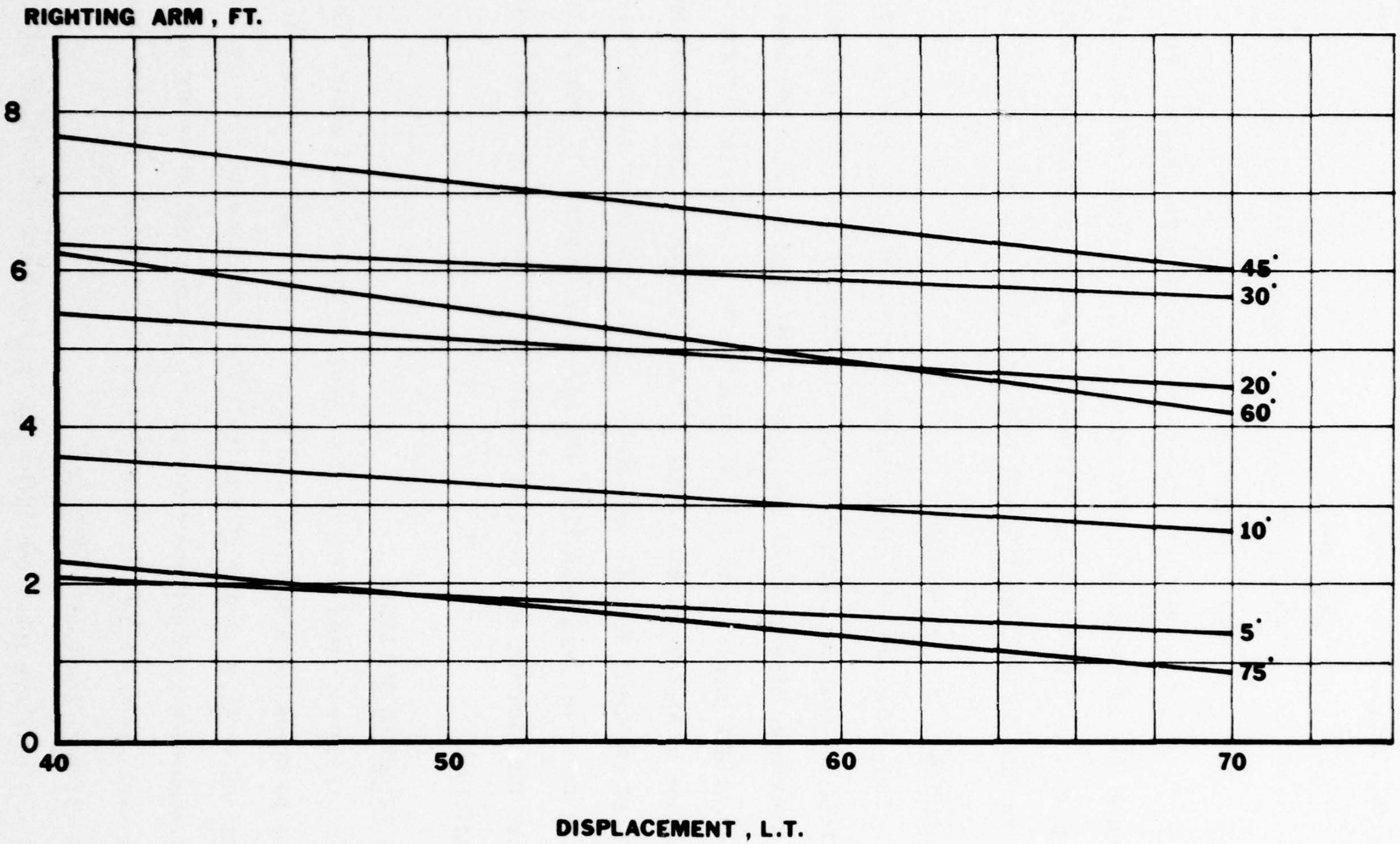


FIGURE 4
CROSS CURVES OF STABILITY (INTACT)

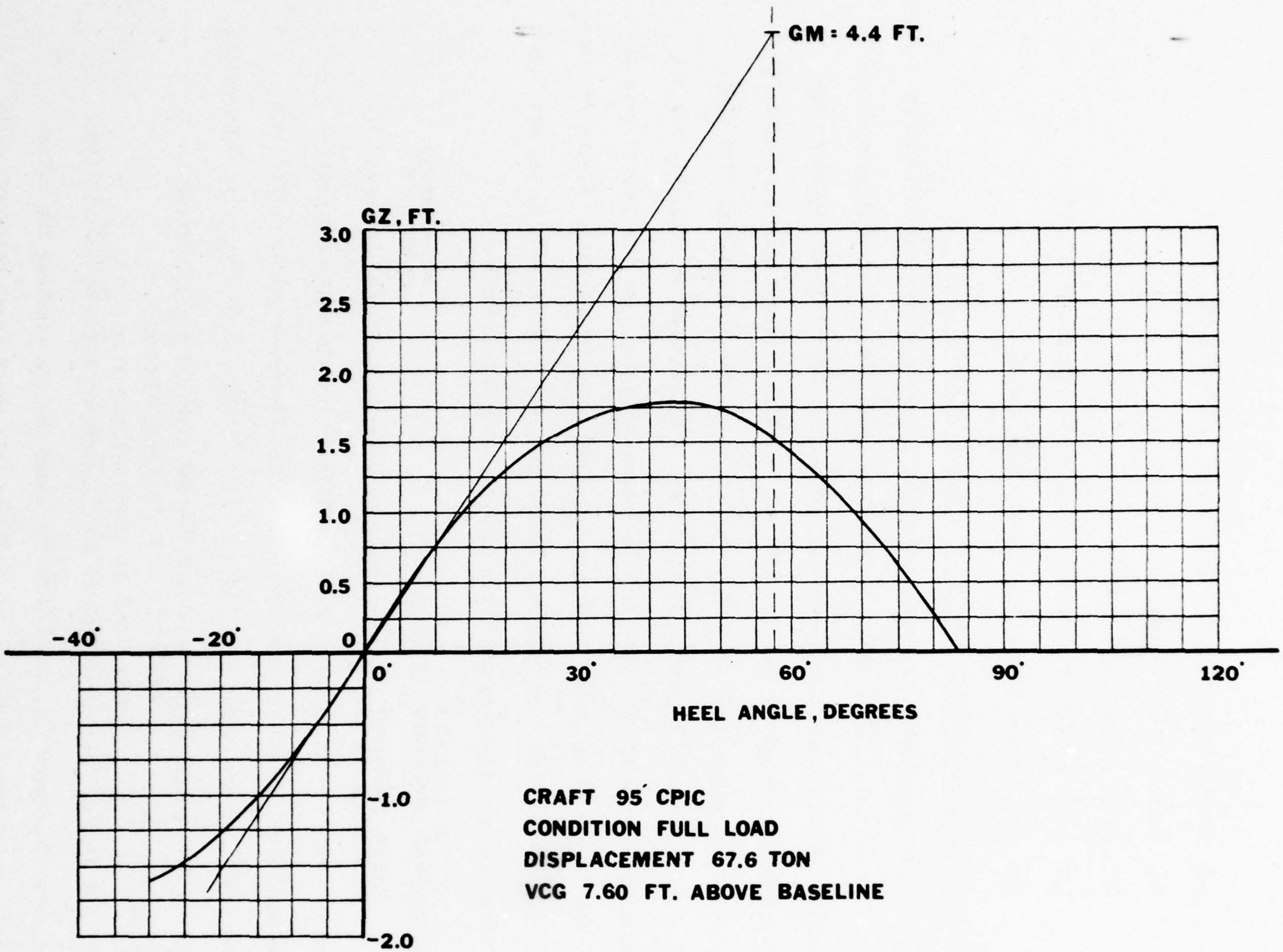


FIGURE 5

RIGHTING ARM CURVE

(a) Initial stability for small angles of heel, GM, 4.4 ft

(b) Maximum righting arm, GZ, 1.76 ft

(c) Angle of maximum GZ, 42°

(d) Range of stability (angle at which GZ returns to 0), 83°

(e) Total dynamic stability (area under curve)

2.5 CORRECTION TO RIGHTING ARM CURVES FOR VCG LOCATION (KG)

As stated above, the cross curves are based on an assumed CG location on the centerplane and, usually, at the base line. This is obviously an unreal location but it serves as a convenient reference. Referring to Figure 6, the correction for actual CG location = KG sin Θ. A significant aspect of stability will become obvious from this correction process. The initial stability (GM), the righting arms (GZ) throughout the range, and the range of stability are all reduced by a rise in CG. This is illustrated in Figure 7 as the general case of CG rise from G to G' rather than the particular case from K to G. Figure 7a shows the curve of GG' sin Θ superimposed on the original righting arm curve, and Figure 7b shows the new righting arm curve corrected for GG' sin Θ.

2.6 CORRECTION FOR OFF-CENTER CG

Weight shifts such as passengers crowding to one side, or cargo off-center reduce the amount of reserve stability. In calm water the craft remains listed at the angle determined by the off-center weight shift; in a seaway it will roll about this angle of list. Figure 8 shows a craft with weight shifted off-center. Figure 9 illustrates the righting arm correction = CG' cos Θ.

A plot of this correction is superimposed on the original righting arm curve in Figure 10a, and Figure 10b shows the new righting arm curve corrected for CG' cos Θ. It will be noted that the lateral shift of weight increases the stability for rotations away from the initial list.

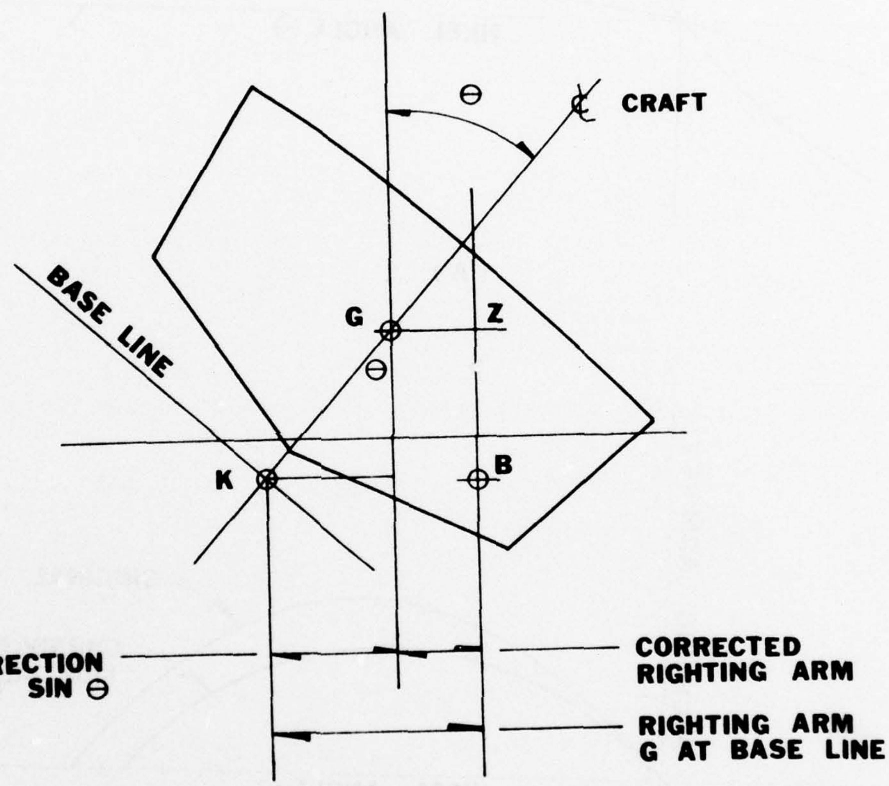


FIGURE 6

CORRECTION FOR VCG LOCATION
(INITIALLY ASSUMED AT BASE LINE)

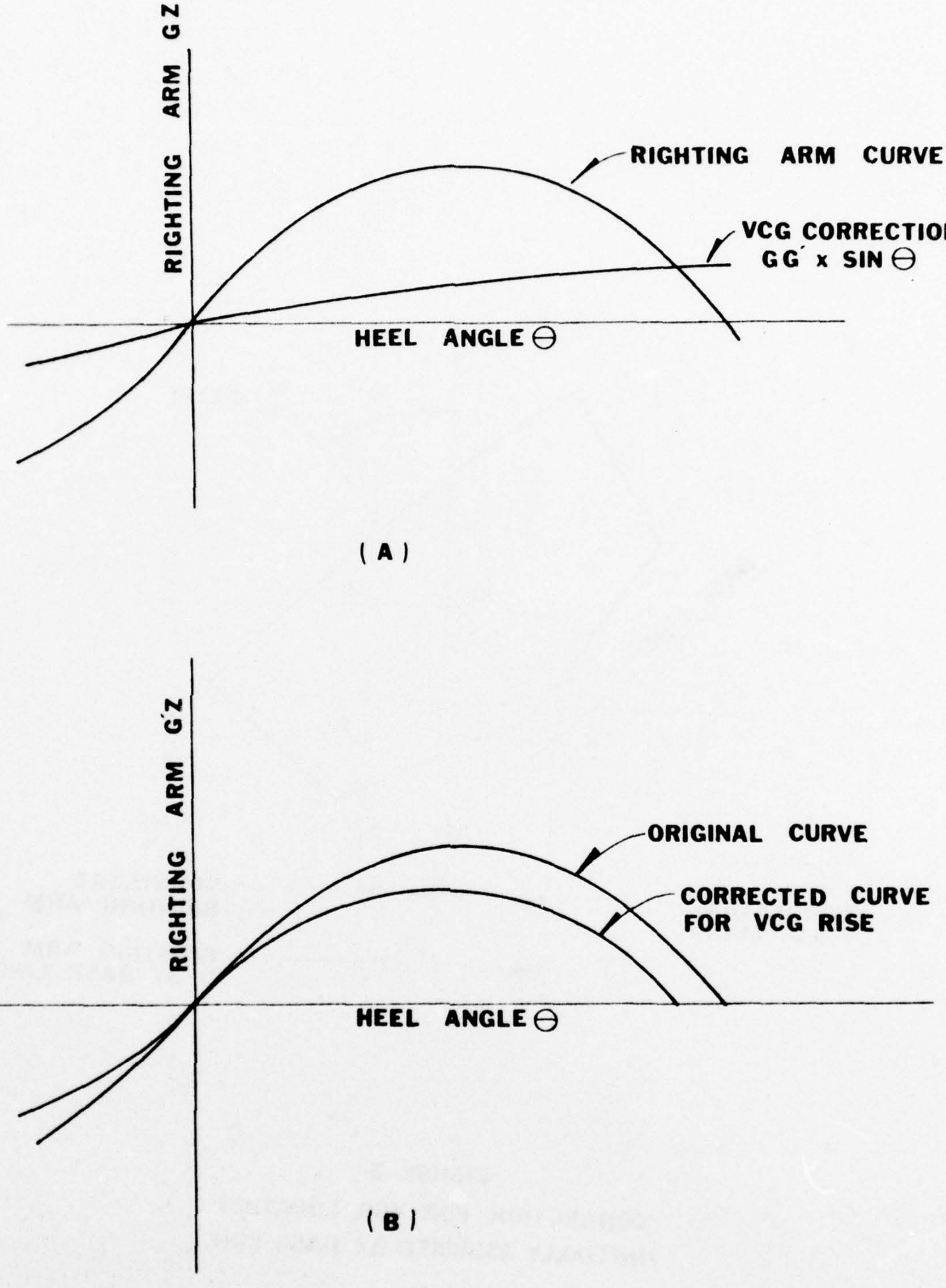


FIGURE 7
RIGHTING ARM CURVE & VCG CORRECTION

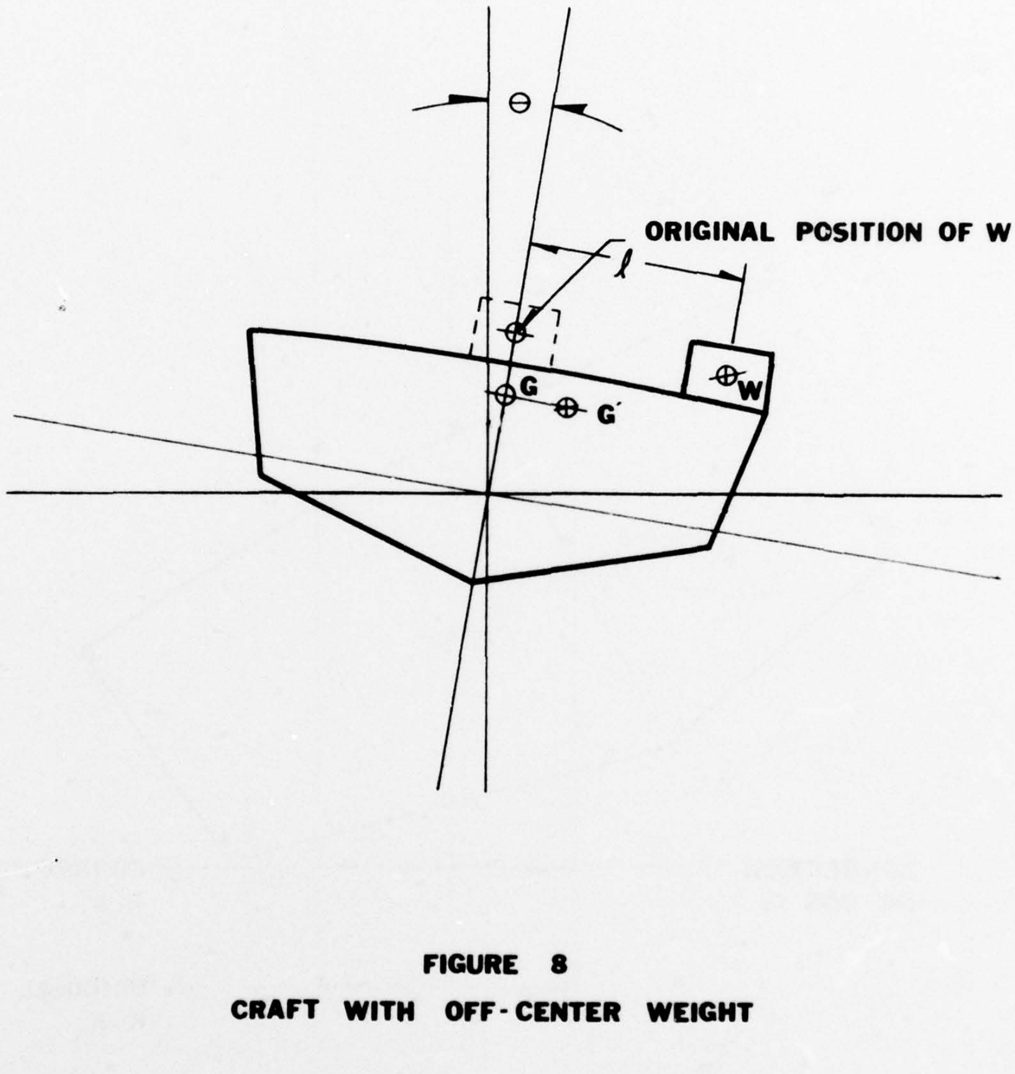


FIGURE 8
CRAFT WITH OFF-CENTER WEIGHT

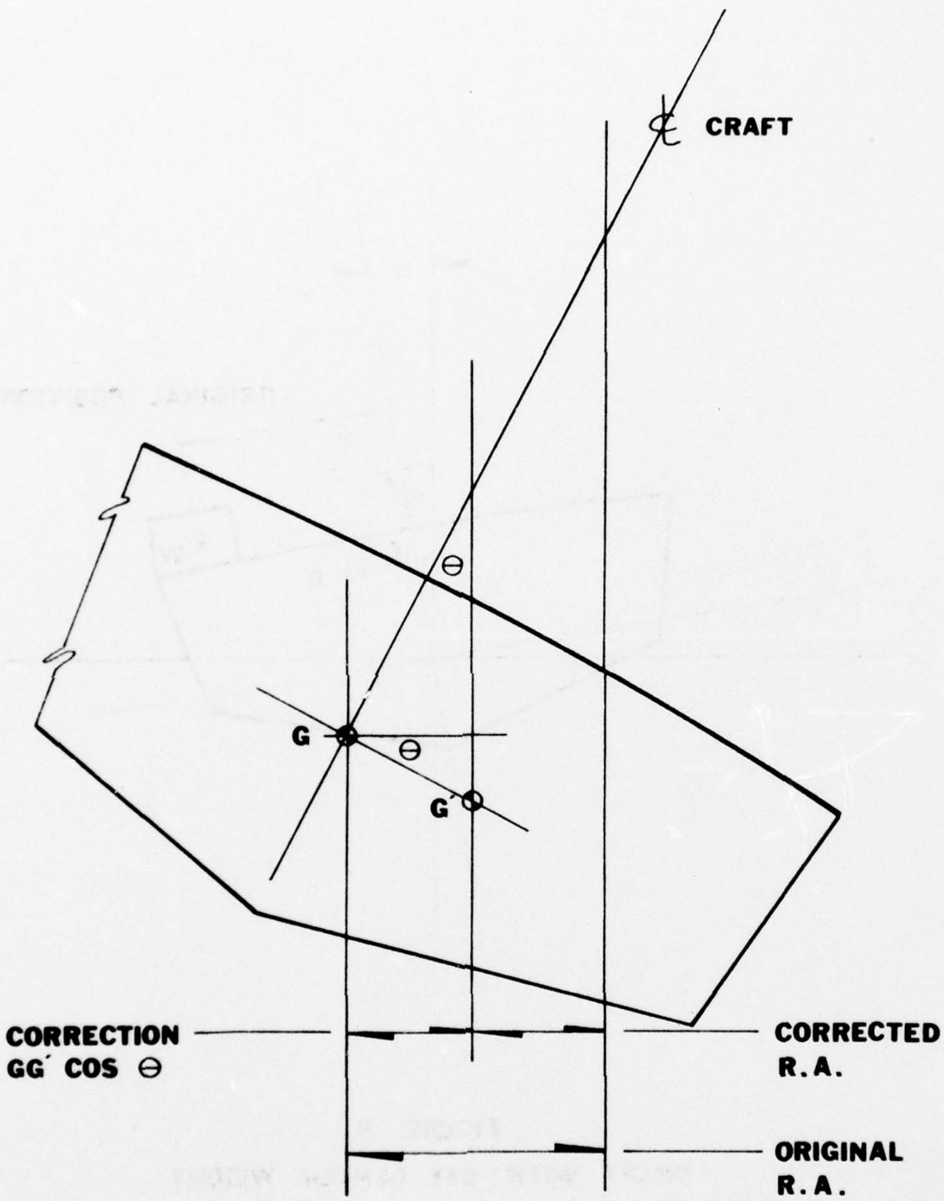


FIGURE 9
CORRECTION FOR OFF-CENTER CG

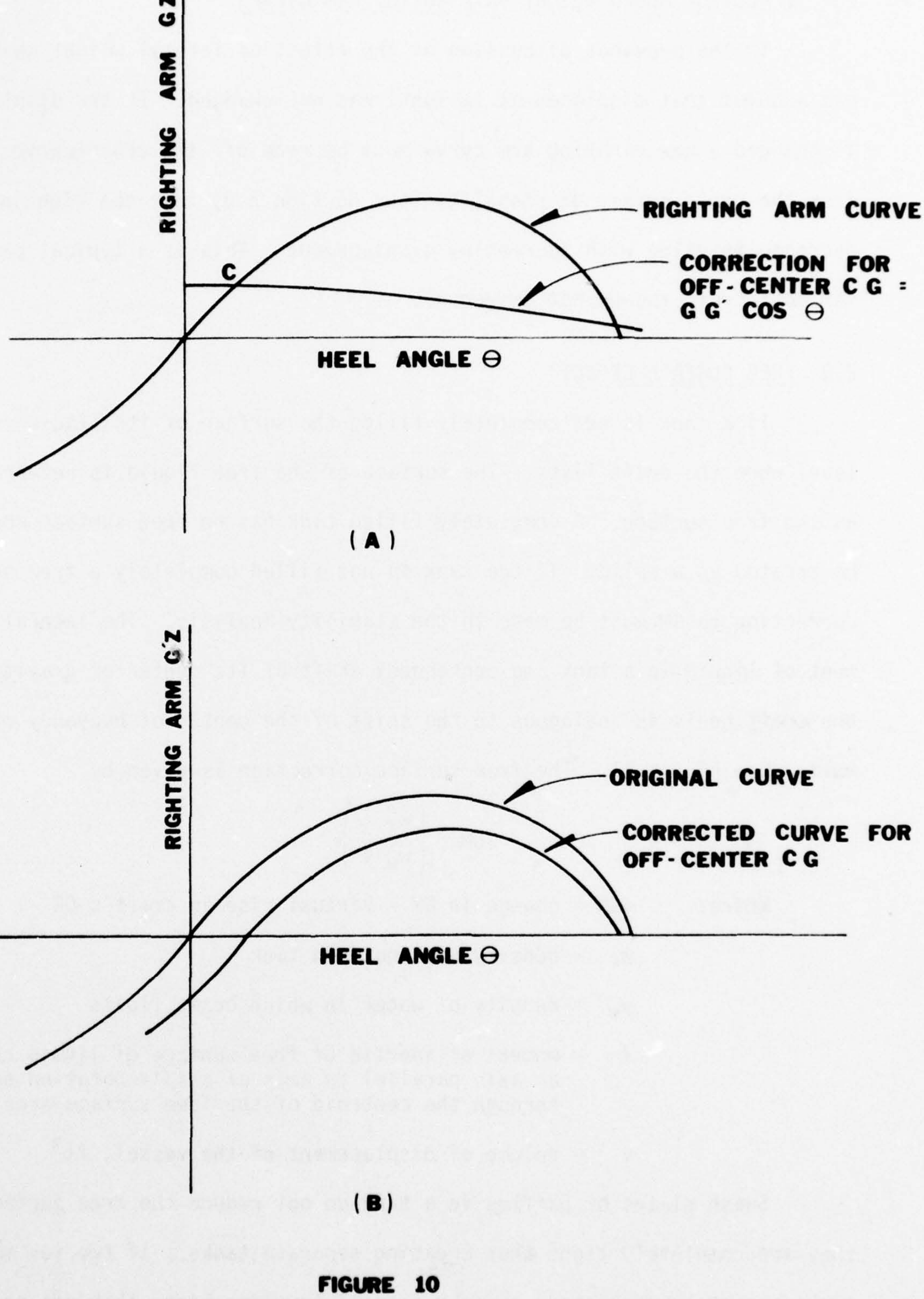


FIGURE 10
RIGHTING ARM CURVE & OFF-CENTER CORRECTION

2.7 EFFECT OF ADDED WEIGHT ON RIGHTING ARM CURVES

In the previous discussion of the effect of lateral weight shift it was assumed that displacement (weight) was not changed. If the displacement is changed a new righting arm curve must be read off the cross-curves. Note from the cross curves of stability (see Section 2.3) that the righting arms decrease in value with increasing displacement. This is a typical pattern for most craft though not universal.

2.8 FREE SURFACE EFFECT

If a tank is not completely filled the surface of its liquid remains level when the craft lists. The surface of the free liquid is referred to as the free surface. A completely filled tank has no free surface and can be treated as a solid. If the tank is not filled completely a free surface correction to GM must be made in the stability analysis. The lateral movement of liquid in a tank and consequent shift of its center of gravity when the craft heels is analagous to the shift of the center of buoyancy of the hull. See Figure 11. The free surface correction is given by

$$\delta GM = \left(\frac{w_\ell \, i}{w_w \, \nabla} \right)$$

Where:

δGM = change in GM = virtual rise in craft's CG

w_ℓ = density of liquid in tank

w_w = density of water in which craft floats

i = moment of inertia of free surface of liquid about an axis parallel to axis of ship's rotation and through the centroid of the free surface area, ft^4.

∇ = volume of displacement of the vessel, ft^3.

Swash plates or baffles in a tank do not reduce the free surface unless they are completely tight thus creating separate tanks. If two (or more) tanks are cross connected, even by a small leveling line, they act as a single tank for free surface effect and the moment of inertia of the total surface

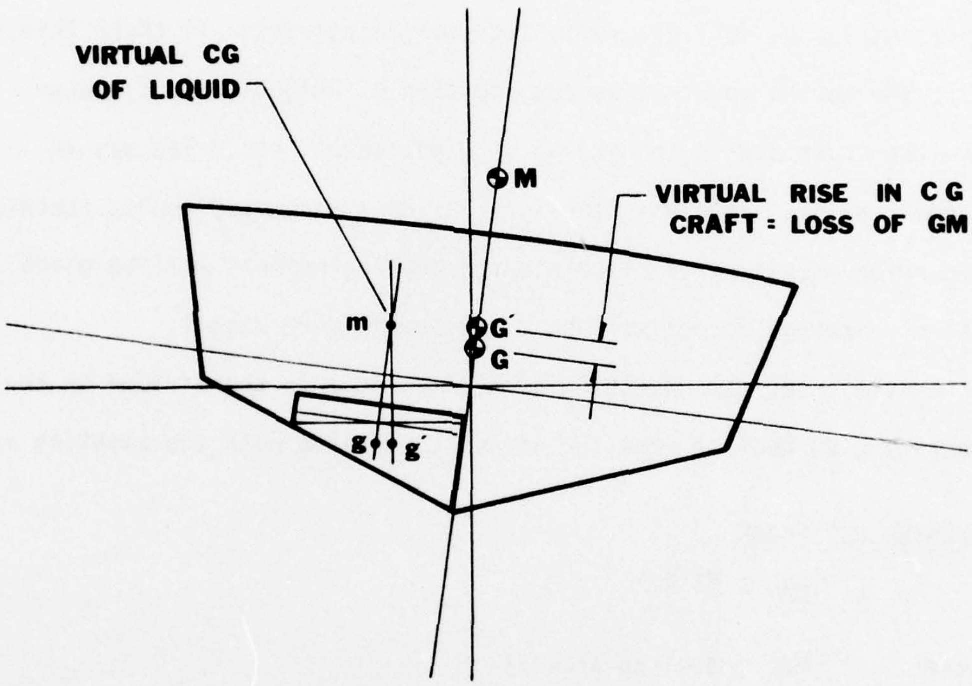


FIGURE 11
FREE SURFACE EFFECTS

area about a longitudinal axis through the combined centroid of surface area must be used for i in the above equation.

If there are large, deep tanks, it is sometimes necessary to correct the vertical and transverse CG of the craft at several (large) angles of heel to obtain a righting arm correction for movement of loose liquid in the tank.

3.0 UPSETTING FORCES

Upsetting forces fall generally into two categories: 1) those internal to the craft due to the movement and/or addition of weights, and 2) those external to the craft due to the action of wind, waves, etc. The way in which internal changes influence stability has been discussed above; therefore, only the equation necessary to calculate the heeling moments will be given. The effects of external forces will be discussed in more detail.

For convenience, the upsetting or heeling moments are divided by the displacement to give heeling arms for direct comparison with the righting arms.

3.1 OFF-CENTER PASSENGERS

$$HA = \frac{Wa \cos \Theta}{\Delta}$$

Where: HA = heeling arm, ft

W = weight of passengers, lb

a = distance from ℄ craft to center of gravity of passengers, ft

Δ = displacement, lb

Θ = heel angle

Assume:

- each passenger occupies 2 sq. ft;
- each passenger weighs 165 lbs, or as specified for the particular case;

- all passengers have moved to one side as far as possible. See discussion of Reference 1 by James B. Robertson, Jr.

3.2 LIFTING HEAVY WEIGHTS OVER THE SIDE

If the weight to be lifted has not been included in the craft's weight calculation, a righting arm curve must be plotted for a displacement which includes the lifted weight, assumed to be added at the VCG (pole height) for which the cross curves are plotted.

If the weight lifted is free to swing on the hoisting cable, the weight will always act downward through the point of attachment on the boom. This has the same effect as locating the entire weight at the point of attachment. Therefore the vertical center of gravity location (VCG) must be corrected for the addition of the weight at that height. For this purpose the weight is initially assumed to be on the centerline. Then a further correction is made for the lateral shift of the weight out to the actual point of attachment on the boom. See Figure 12. If the load is restrained against swinging, its effective vertical location is as shown in Figure 13.

The steps are (referring to Figures 12 and 13):

(a) Add weight at axis for cross curves.

(b) Move weight, W, up to height, h, above the base line. The new VCG is

$$KG' = (\Delta KG + W\,h)/\ (\Delta + W)$$

and the correction to the righting arm is

$$KG' \sin\ \Theta.$$

(c) Move the weight a distance, ℓ, off center. The shift of the vessel's center of gravity is

$$G'G'' = W\ell\ /\ (\Delta + W)$$

and the correction to the righting arm is

$$G'G'' \cos \Theta.$$

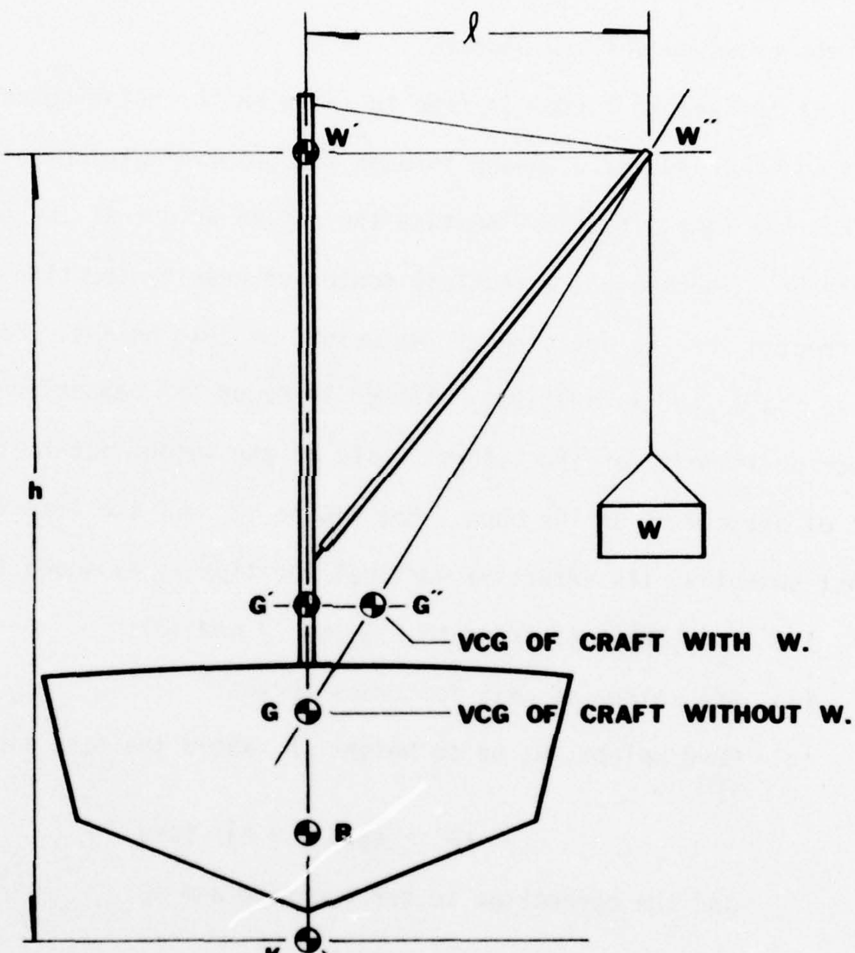
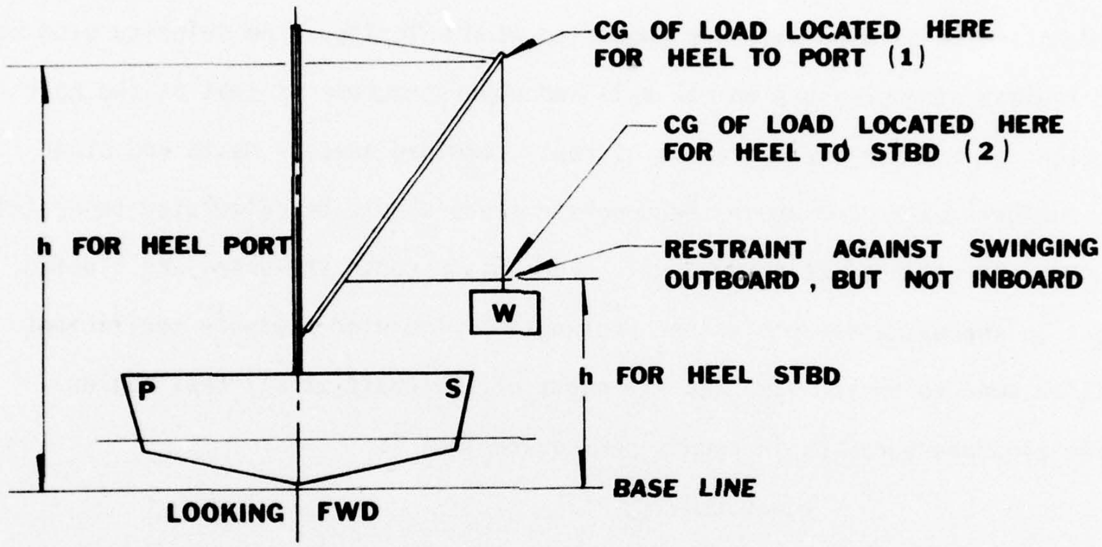


FIGURE 12

HOISTING WEIGHTS ALONGSIDE



THIS STIUATION CAUSES A DISCONTINUITY IN THE RIGHTING ARM CURVE

(1) THIS CONDITION IS OF INTEREST ONLY IN THE CASE OF ROLLING IN WAVES, BECAUSE HEEL TO PORT CANNOT OCCUR IN CALM WATER

(2) THIS CONDITION IS OF PRIMARY INTEREST

FIGURE 13

PARTIAL RESTRAINT OF SWINGING LOAD

3.3 WIND HEELING

Wind velocity increases with height above the water because of ground effect. It is conventional to measure velocity at a height of 10 meters (33 ft approx). Figure 14 shows the decrease in velocity below this level for a 100 kt wind. The velocities also represent percentages of the velocity at 10 meters to be used with any specified wind velocity. The velocity used to calculate wind pressure on the hull and superstructure is that at the half height of the projected profile of these combined areas. Masts and other structures extending above the superstructure should be calculated separately using the velocity at their level. For this purpose the areas are blocked out in approximately equivalent rectangles. The wind pressure coefficient is assumed to be the same for all parts of the craft at all heel angles. The wind pressure, p, in pounds per square foot is

$$p = 0.004 \, V_k^2$$

Where V_k = wind velocity in knots at centroid of the area in question

0.004 = a constant to account for both the drag coefficient and the units.

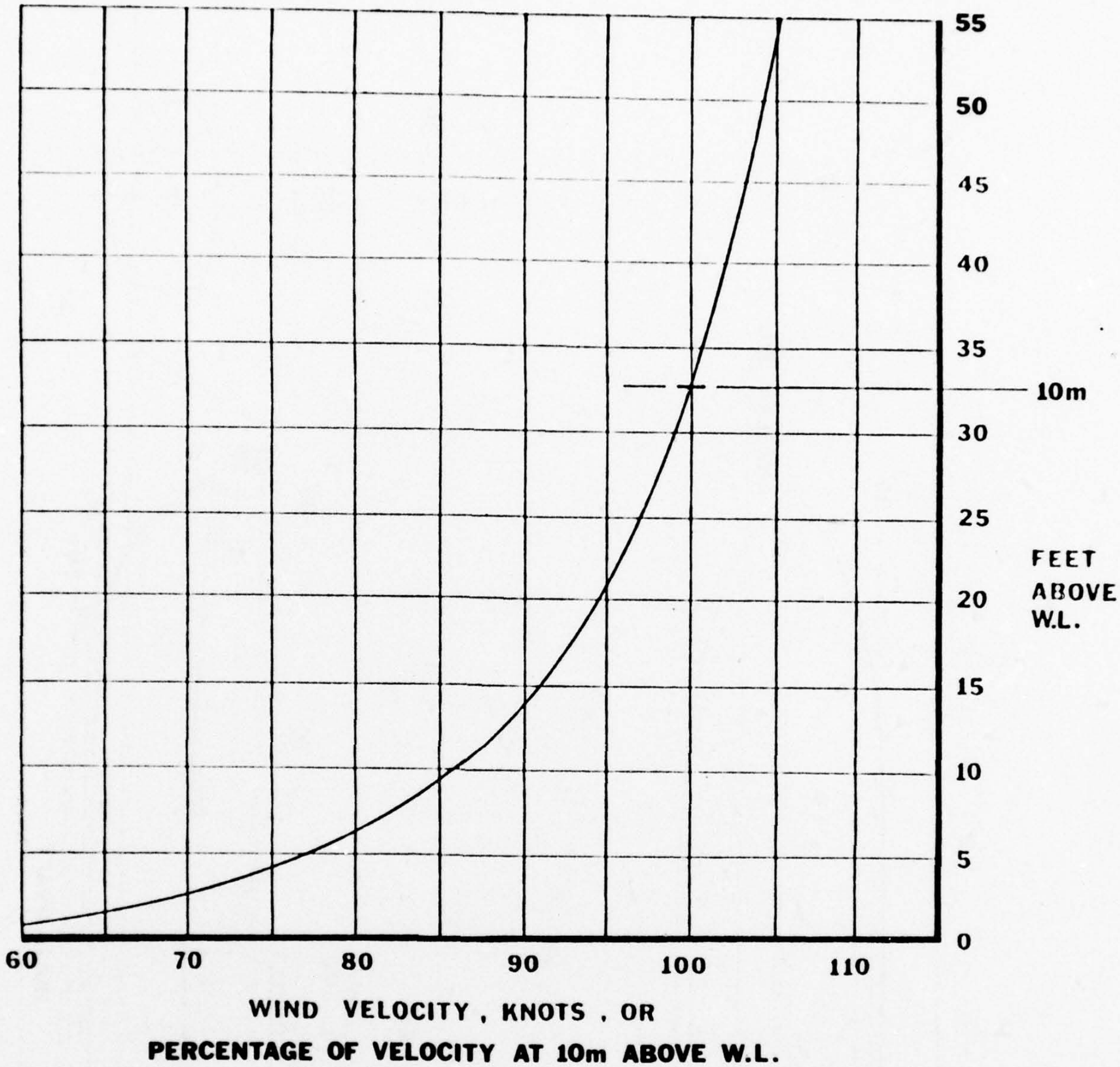
The projected area on which the wind is assumed to act is taken from an end view of the blocked out rectangular profile planes described above. Figures 15 and 16 illustrate this. The moment of area about the half draft point is calculated at each of several heel angles and multiplied by the wind pressure, p, as calculated above, to give heeling moments. These are divided by the displacement (in pounds, to be consistent with the wind pressure), to produce heeling arms:

$$HA = p \, A \, h \, / \, \Delta$$

Where: HA = heeling arm, ft

A = the total projected area, ft^2

h = the height of the centroid of the area above the half draft point, ft, as shown in Figure 16 for 90° heel.



EXAMPLE:

CENTROID OF SAIL AREA 10′ ABOVE W.L.

DESIGN WIND VELOCITY 60 KNOTS

VELOCITY AT 10′ $= \frac{85}{100} \times 60 = 51$ KNOTS

FIGURE 14

WIND VELOCITY PROFILE

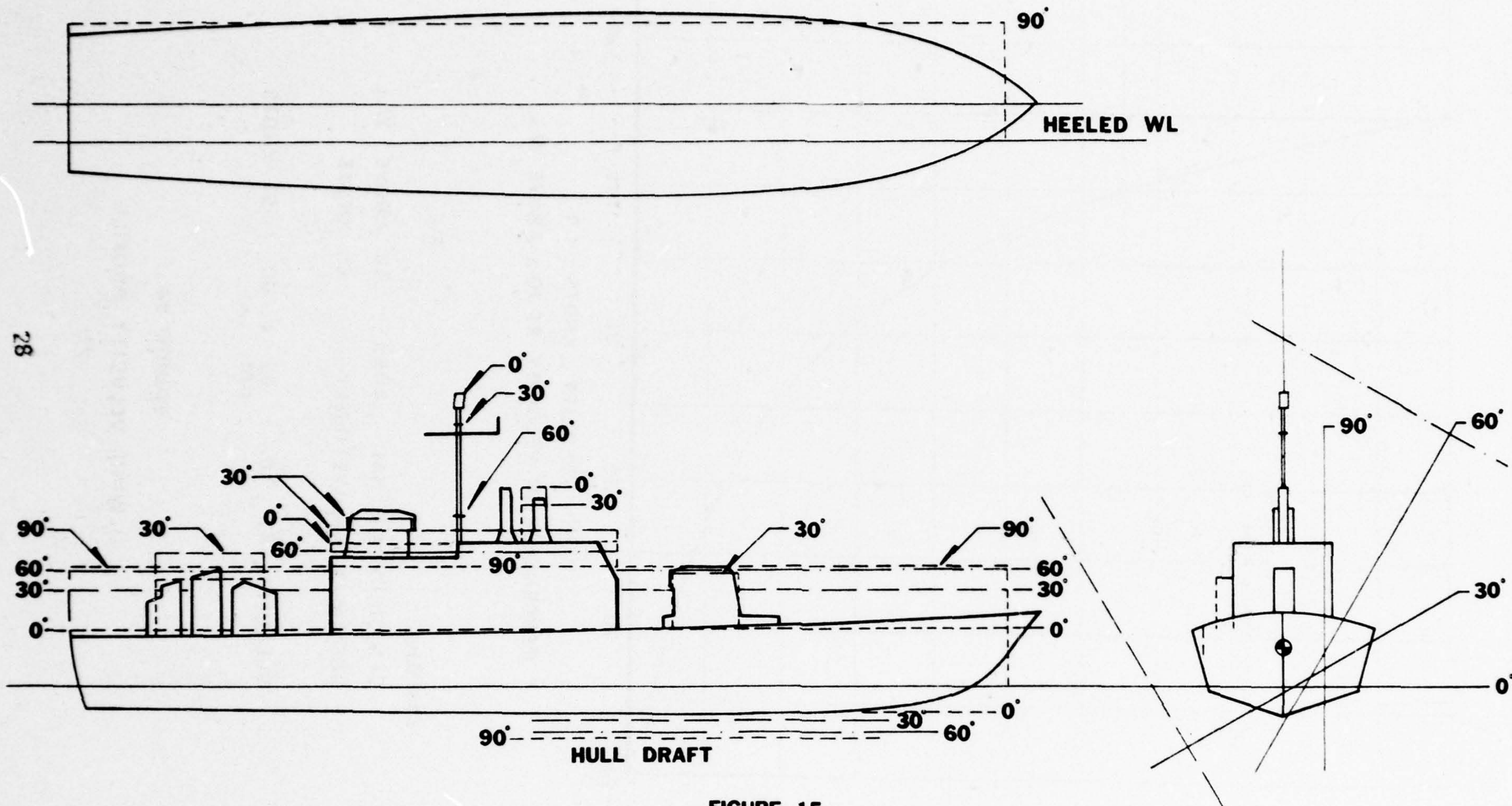


FIGURE 15

DETERMINATION OF PROJECTED SAIL AREA

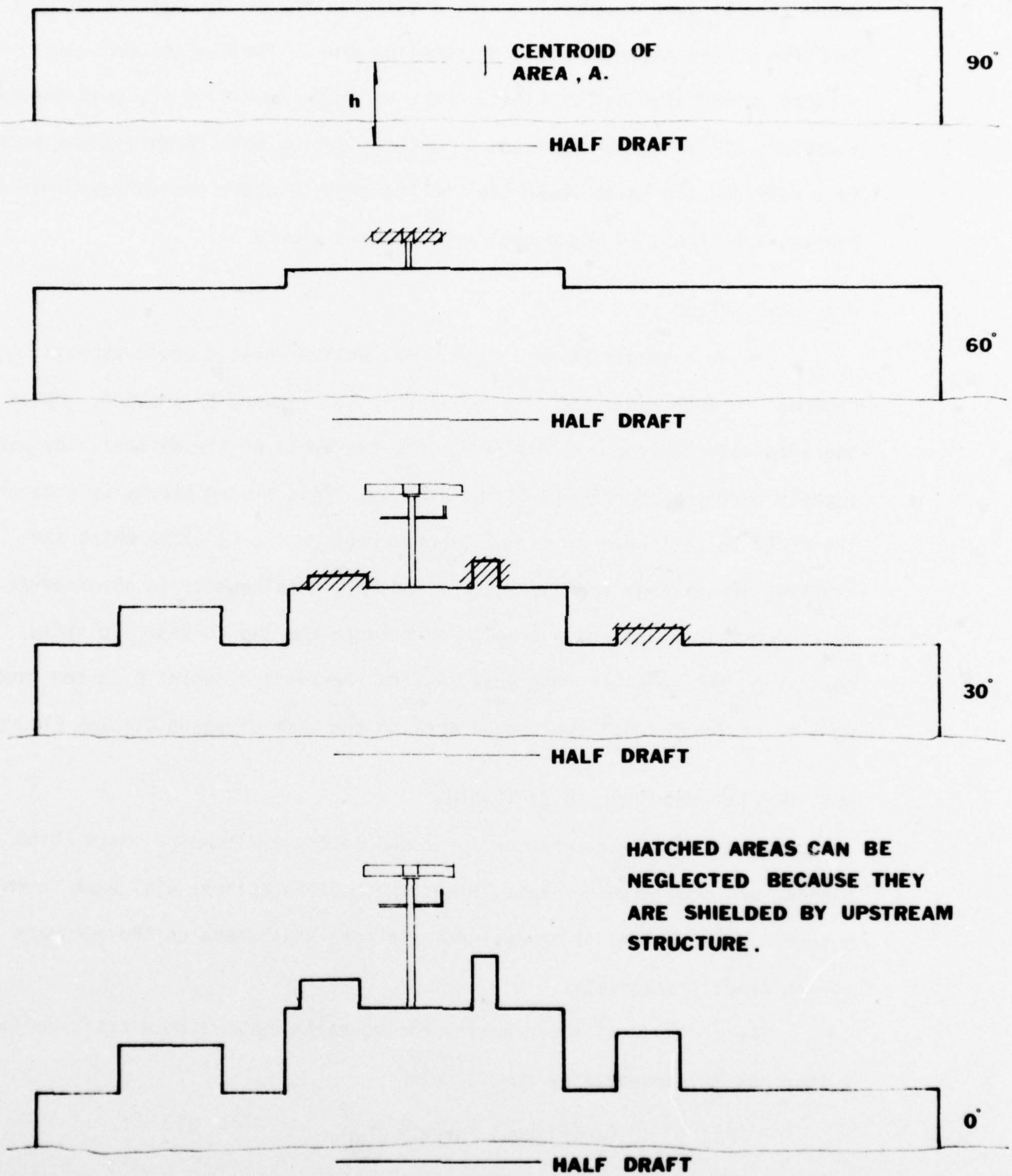


FIGURE 16

PROJECTED SAIL AREA AT SEVERAL HEEL ANGLES

Since this is done at specific heel angles the arm is not multiplied by a function of the angle as for other heeling arms. The heeling arms are plotted on the statical stability curve as shown in Figure 17, thus providing a measure of the energy imparted to a craft during roll to an assumed angle. In a calm sea the craft would heel to the angle C under the influence of the heeling arm shown, if the moment were applied slowly.

3.4 WAVE ACTION

If, in a specified sea state, wave action rolls a craft through θ_r degrees* to each side, the craft will roll to windward to angle A. While the ship returns from a windward roll to the angle of steady heel, the wind imparts energy proportional to the area A_2. This stored energy will cause the craft to roll beyond the equilibrium heel angle, C, after which the righting arm exceeds the heeling arm and rotational energy is absorbed at a rate proportional to the accrued area between the two curves. To avoid capsizing, the total of this area, A_1, to the right of point C in the figure must be at least equal the shaded area to the left of point C. See Figure 17.

3.5 HEELING ARM PRODUCED BY TURNING

This is usually a factor for round bottom craft only. Hard chine planing and semi-planing craft, almost without exception, will bank in on a turn. Nevertheless it is advisable to make this check on the adequacy of the craft's stability.

The centrifugal force acting horizontally outward on a craft during a turn may be expressed by the formula:

$$\text{Centrigugal Force} = \frac{\Delta\, v^2}{gR}$$

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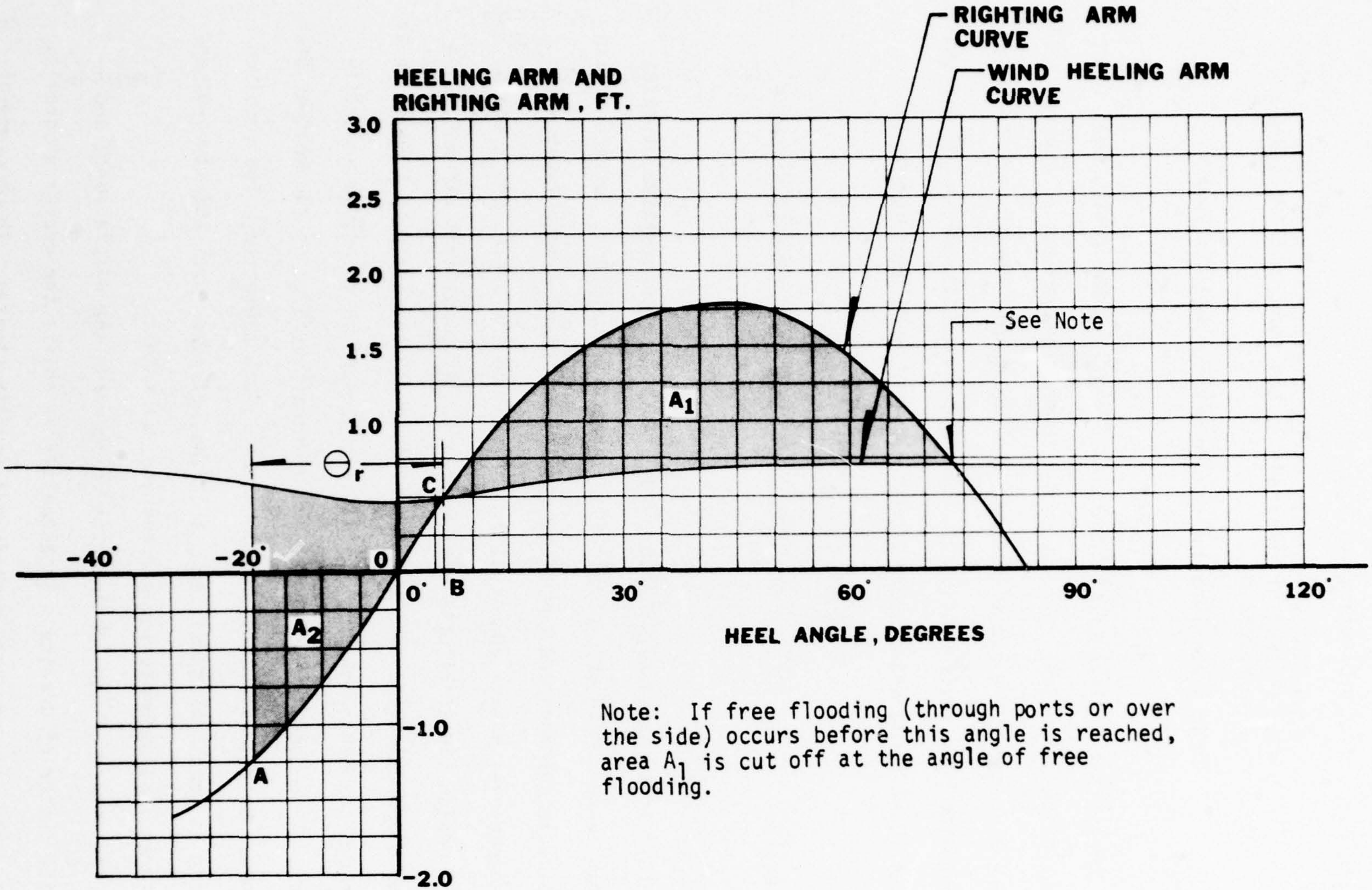
*Described in Section 5.1.1.



Note: If free flooding (through ports or over the side) occurs before this angle is reached, area A_1 is cut off at the angle of free flooding.

FIGURE 17
WIND HEELING ARM CURVE

Where: Δ = Displacement, lb

υ = linear velocity of the craft, ft/sec. This is the speed of the craft in the turn, not the speed of approach.

g = Acceleration due to gravity, 32.2 ft/sec^2

R = turning radius, ft

The lateral resistance of the hull is equal to the centrifugal force and opposite in direction. The lever for the heeling moment is the vertical distance, a, between the craft's CG and the center of lateral resistance of the underwater body (half draft), ft. If this is multiplied by the expression for centrifugal force and divided by displacement, the heeling arm is

$$HA = \frac{\upsilon^2 a \cos \theta}{g R}$$

Where: θ = angle of inclination and other symbols as above.

3.6 TOPSIDE ICING

This is an extremely variable condition. Ice accumulates at rates which vary with atmospheric conditions, surface orientation, surface finish (some plastic coatings and coverings accumulate ice at a much lower rate than conventional paints and metals), location on the craft, craft speed and hull design (as it affects deck wetness). If conditions warrant it, a reasonable approximation of the icing effects can be made with a model in an atmospheric chamber. However, the usual procedure is to assume a certain thickness of ice on all horizontal and vertical surfaces on the weather deck and above. Masts, lifelines, fittings, etc., are neglected. The required thickness is sometimes specified. If it is not, two cases are studied; one for a three inch accumulation and one for six inches.

The effect of topside icing is to increase the displacement and raise the center of gravity. In actuality it shifts the center of gravity off the centerline but this case is not usually studied. The procedures for

making these calculations have been outlined in Sections 2.5 and 2.7 above. For this purpose, the approximate average density of ice is taken as 56.7 lb per cubic ft.

Since the stability criteria for topside icing (Section 5.1.5) are based on wind heel, it is sometimes necessary to limit the beam winds in which the craft may operate when iced. The amount of restriction is determined by adjusting the wind heeling arm curve downward until the craft in the iced condition meets the criteria. After this is done the equivalent wind velocity is calculated as follows:

$$V_i = V_o \times \left(\frac{HA_i}{HA_o}\right)^{1/2}$$

Where:

V_i = Maximum allowable wind velocity with specified or assumed thickness of ice.

HA_i = Heeling arm at 0° heel from the above trial and error procedure.

HA_o = Heeling arm at 0° heel for the design wind condition, no ice.

V_o = Design wind velocity, no ice, knots.

The criteria are given in Section 5, below.

4.0 DAMAGE STABILITY

The calculations for damage stability have been completely computerized. A sample of the output is shown in Figure 18. Figure 19 illustrates the quantities which are tabulated in Figure 18. The righting arms are calculated for a specific condition of loading, including the correct VCG and LCG, therefore no corrections have to be made. The righting arms from the print-out are plotted against heel angle and compared to the applicable stability criteria.

SHIP- SHCP SAMPLE SHIP S.S.SUSAN GAIL SERIAL NUMBER- 717 DATE- 6/30/75

DAMAGED STATICAL STABILITY CALCULATIONS

INPUT COMPARTMENT DESCRIPTIONS

ID	NAME	SYM	PERM	X1D	X2D	Y1D	Y2D	Z1D	Z2D
101	ENGINE ROOM 18-36 FEE	-0	.90	118.00	168.00	9999.99	9999.99	18.00	36.00
102	ENGINE ROOM 4-18 FEET	-0	.70	118.00	168.00	9999.99	9999.99	4.00	18.00
200	FIRE ROOM	-0	.90	168.00	216.00	9999.99	9999.99	9999.99	36.00
201	WATER TK. FULL 1/3 LV	1	.03	168.00	216.00	9999.99	9999.99	9999.99	12.00
202	DEDUCT FIREROOM FROM 2	1	-.03	168.00	216.00	9999.99	9999.99	9999.99	12.00
203	WATER TK. AT 2/3 TOP	1	.98	168.00	216.00	9999.99	9999.99	12.00	36.00
204	DEDUCT FIREROOM FROM 2	1	-.98	168.00	216.00	9999.99	9999.99	12.00	36.00
303	STORE ROOM	-0	.85	216.00	256.00	9999.99	20.00	24.00	36.00
304	FUEL OIL FULLBOTTOM	-0	.98	216.00	256.00	9999.99	9999.99	9999.99	24.00
306	FUEL OIL FULL	-0	.98	216.00	256.00	20.00	9999.99	24.00	36.00

CONDITION 1 COMPARTMENTS INCLUDED 101 102 200 201 202 203 204 303 304 306

COMPARTMENT AND INTACT SHIP PROPERTIES AT BALANCE CONDITION

HEEL	DRAFT	TRIM	I.D.	DISPL	VOLUME	TCB	VCB	LCB
20.00	30.029	6.791	101	1239.896	43396.38	17.026	25.791	6.705
			102	839.138	29369.82	4.434	11.396	6.775
			200	1746.441	61125.43	8.489	21.610	-41.428
			201	7.730	270.54	11.345	8.255	-40.168
			202	-2.966	-103.80	7.840	9.874	-33.214
			203	1338.463	46846.21	22.293	24.318	-41.777
			204	-1166.562	-40823.67	13.385	24.635	-41.597
			303	295.673	10348.56	5.561	28.715	-35.303
			304	915.163	32030.71	1.333	16.432	-43.542
			306	281.428	9849.99	30.542	30.266	-34.516
			INT	11978.741	419255.94	10.613	21.793	-4.157

CONDITION 1 COMPARTMENTS INCLUDED 101 102 200 201 202 203 204 303 304 306

NET DAMAGED SHIP PROPERTIES

DISPL	LCG	POLE HT	HEEL	RA	TCB	VCB	LCB	DRAFT	TRIM
7739.81	4.828	26.00	0.00	-.830	-.830	20.501	4.614	33.208	11.609
			5.00	1.182	1.658	20.609	4.633	32.883	10.869
			10.00	3.394	4.335	20.960	4.665	32.134	9.696
			15.00	5.532	6.924	21.532	4.703	31.181	8.339
			20.00	7.555	9.384	22.305	4.745	30.029	6.791
			>30.00	11.253	13.919	24.398	4.811	26.989	3.046
			40.00	14.008	17.523	26.909	4.826	22.859	-.653
			50.00	15.623	20.127	29.506	4.782	17.289	-4.012
			60.00	16.270	21.956	32.110	4.573	8.992	-7.534
			70.00	16.180	23.205	34.773	4.434	-6.279	-13.437

FIGURE 18

SAMPLE DAMAGE STABILITY OUTPUT FROM SHIP HULL CHARACTERISTICS PROGRAM

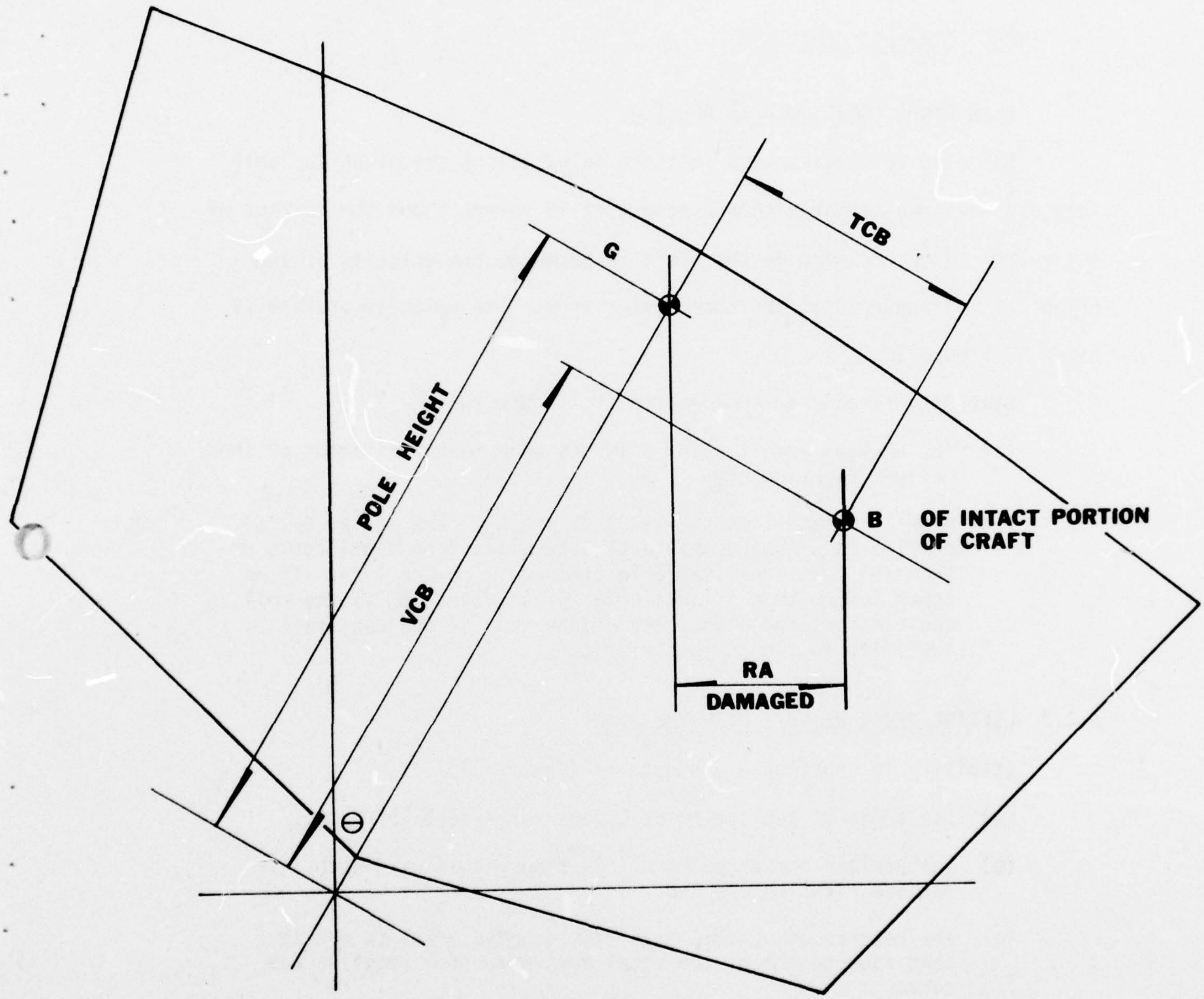


FIGURE 19
DAMAGED CENTER OF BUOYANCY

5.0 STABILITY CRITERIA

These stability criteria are taken from References 1 and 2 which should be consulted for a more complete understanding of the subject.

5.1 INTACT STABILITY CRITERIA

5.1.1 BEAM WINDS COMBINED WITH ROLLING

The wind velocities used in these calculations are given in Table 1. They are measured at the standard height of 10 meters above the surface of the water. Wind pressure on the craft is based on the velocity at the height of the centroid of the above water area. The velocity profile is given in Figure 14.

Stability is considered adequate if (Figure 20):

(a) The heeling arm at point C is not more than six tenths of the maximum righting arm.

(b) Area A_1 is not less than 140% of are A_2. The angle, Θr, of rolling to windward should be determined from model tests or from the best data available from craft of the type. If no other information is available 25° is used. Θ_r is the roll angle associated with fully arisen seas of the sea state specified in the characteristics.

5.1.2 LIFTING HEAVY WEIGHTS OVER THE SIDE

Stability is considered adequate if (Figure 21):

(a) The angle of heel at point C does not exceed 15°.

(b) The heeling arm at point C is not more than six tenths the maximum righting arm and

(c) The reserve of dynamic stability (shaded area) is not less than four tenths of the total area under the righting arm curve.

5.1.3 CROWDING OF PASSENGERS TO ONE SIDE

Stability is considered adequate if (Figure 21):

(a) The angle of heel at point C does not exceed 15°.

Table 1. Wind Velocities

Service	Minimum wind velocity for design purposes (knots)	Minimum Acceptable wind velocity for craft after 5 years in service (knots)
1. Ocean		
(a) Craft which will be expected to weather full force of tropical cyclones. This includes all craft which will move with the amphibious and striking forces	100	90
(b) Craft which will be expected to avoid centers of tropical disturbances	80	70
2. Coastwise		
(a) Craft which will be expected to weather full force to tropical cyclones	100	90
(b) Craft which will be expected to avoid centers of tropical disturbances, but to stay at sea under all other circumstances of weather	80	70
(c) Craft which will be recalled to protected anchorages if winds over Force 8 are expected	60	50
3. Harbor	60	50

Taken from Reference 1 & 2

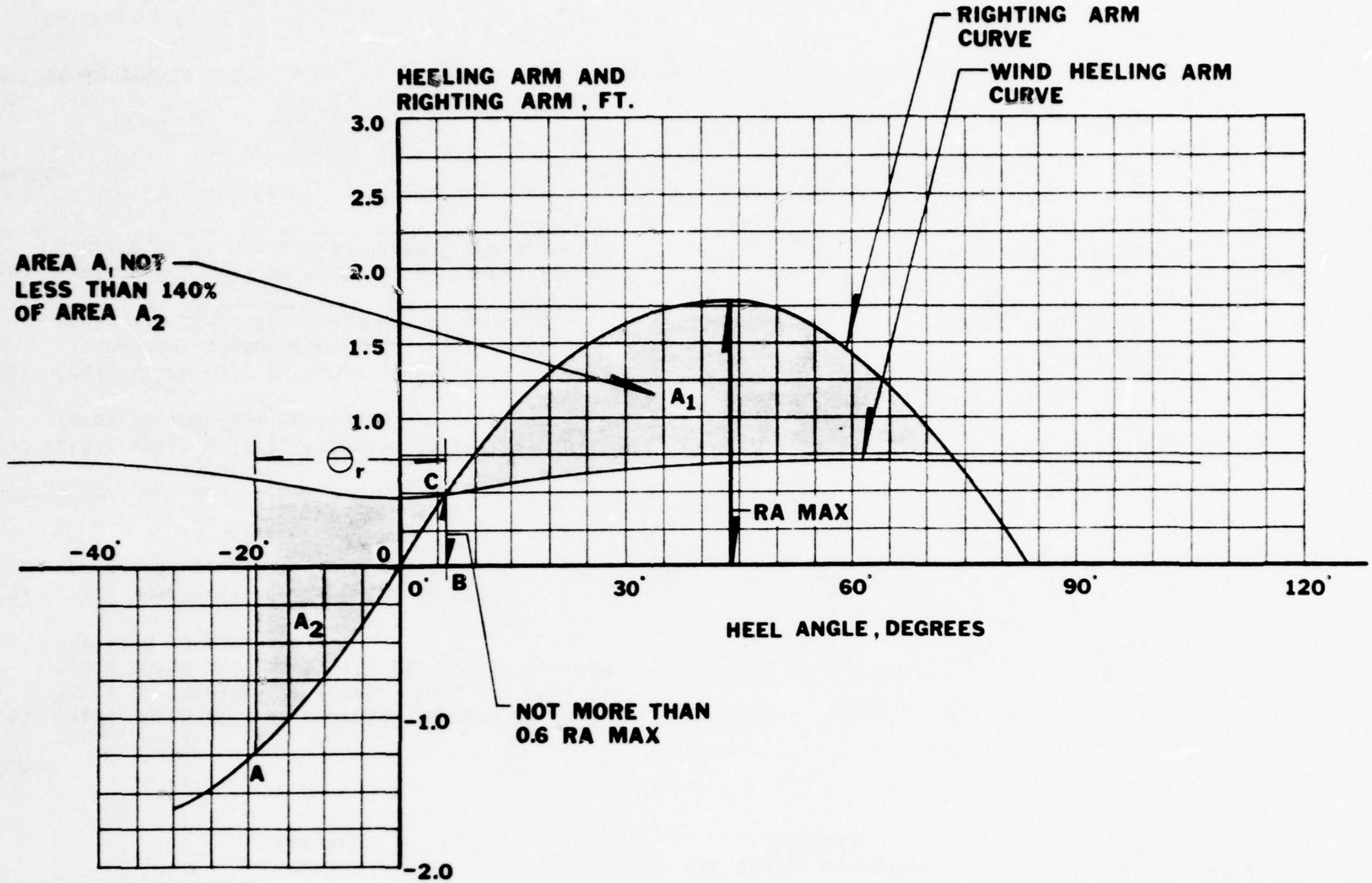


FIGURE 20
CRITERIA FOR BEAM WINDS
COMBINED WITH ROLLING

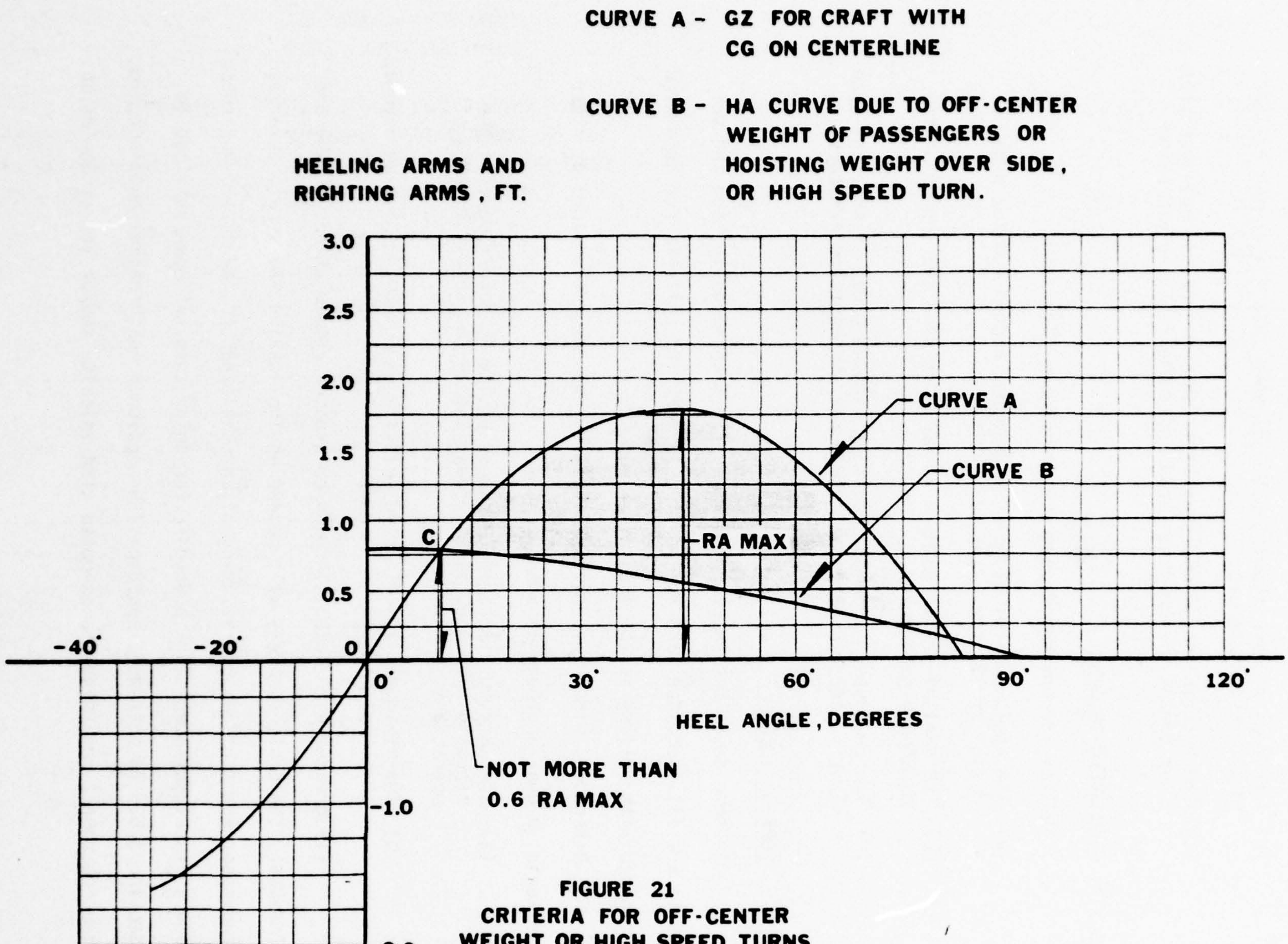


FIGURE 21
CRITERIA FOR OFF-CENTER WEIGHT OR HIGH SPEED TURNS

(b) The heeling arm at point C is not more than six tenths of the maximum righting arm.

(c) The reserve of dynamic stability (shaded area) is not less than four tenths of the total area under the righting arm curve.

5.1.4 HIGH-SPEED TURNING

Stability is considered adequate if (Figure 21):

(a) The angle of heel at point C does not exceed 10° for a new design or 15° for craft in service.

(b) The heeling arm at point C is not more than six tenths of the maximum righting arm.

(c) The reserve of dynamic stability (shaded area) is not less than four tenths of the total area under the righting arm curve.

5.1.5 TOPSIDE ICING

In some cases the thickness of ice, the wind velocity, and the sea state are all specified, and the craft must meet the criteria for beam wind combined with rolling in the iced condition.

Otherwise, since the craft's stability has been determined by other criteria, a dual approach is used:

(a) The maximum allowable thickness of ice is determined for the probable wind conditions prevailing in the specified area of operations, or

(b) The maximum allowable wind velocity is determined for an assumed thickness of ice.

(If greater wind velocities and/or greater accumulations of ice are forecast, the craft's safety will depend on its leaving the area.) Usually two cases are studied: one assuming 3" and the other 6" ice on all horizontal and vertical surfaces. The procedure for doing this has been outlined in Section 3.6. In this dual approach, the designer must receive guidance from the "customer" regarding the expected wind velocity and/or ice accumulation.

5.2 DAMAGE STABILITY CRITERIA

Reference 1 states that new designs without side protective systems must meet the following subdivision criterion:

(a) Seagoing craft less than 100 ft in length shall be capable of withstanding, as a minimum, the flooding of any single main compartment.

(b) Craft between 100 and 300 ft in length shall be capable of withstanding, as a minimum, the flooding of any two adjacent main compartments.

Every effort is made to exceed this minimum requirement even for craft under 100 ft, because damage is almost as likely to occur at a bulkhead (thus flooding two compartments) as between bulkheads.

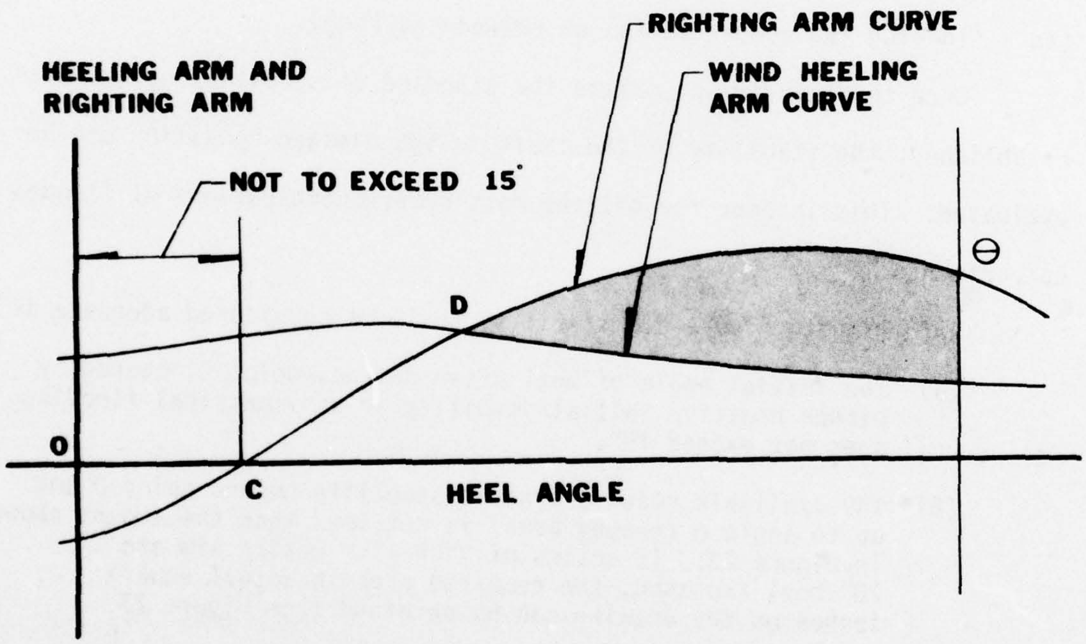
Once this criterion (called the standard of subdivision) has been established, the stability of the craft in the damaged condition can be evaluated. This is done for all the most severe combinations of flooded compartments.

Referring to Figure 22, stability shall be considered adequate if:

(a) The initial angle of heel after damage, point C, caused by either negative initial stability or unsymmetrical flooding, does not exceed 15°.

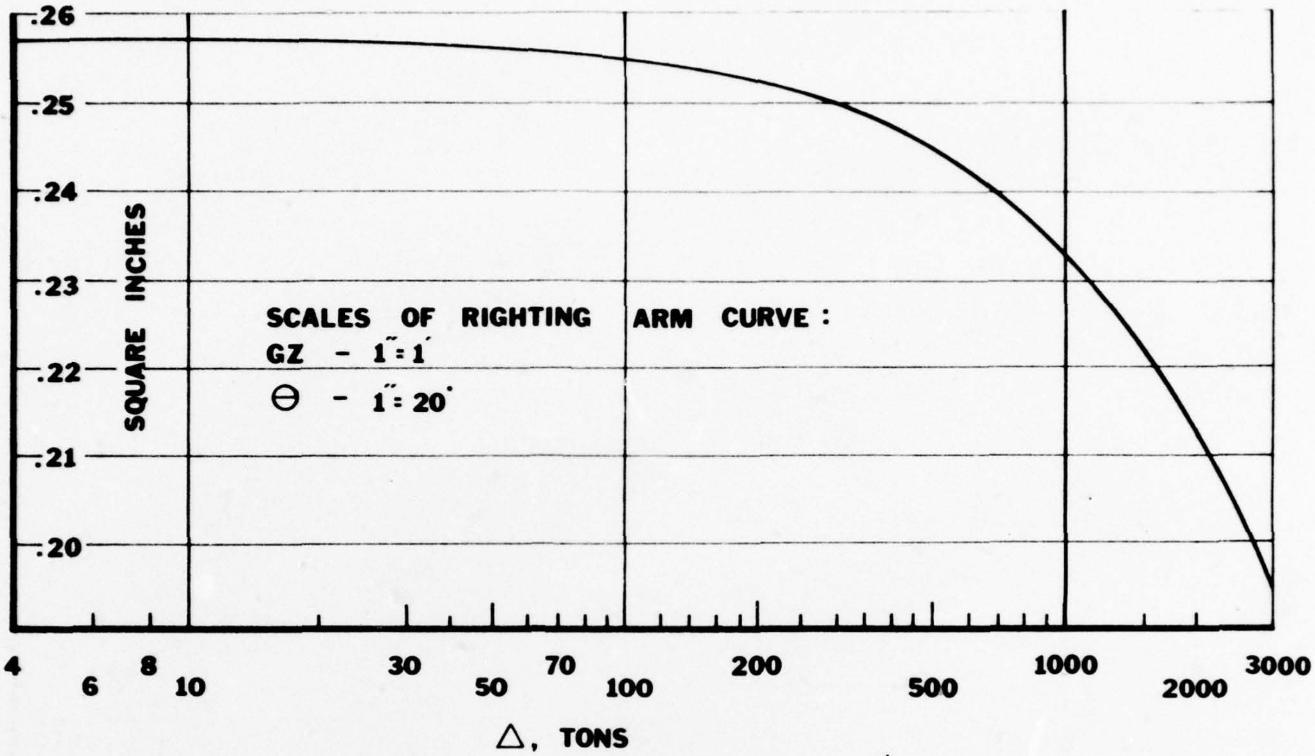
(b) The available reserve dynamic stability beyond point D and up to angle Θ (shaded area) is not less than the amount shown in Figure 23. If scales of 1" = 1' righting arm and 1" = 20° heel are used, the required area in actual square inches on the drawing can be obtained from Figure 23.

The angle, Θ, in Figure 22 is 45° or the angle at which unrestricted flooding occurs, whichever is less.



Θ AND A AS DEFINED IN SECTION 5.2

FIGURE 22
DAMAGED STABILITY CRITERIA



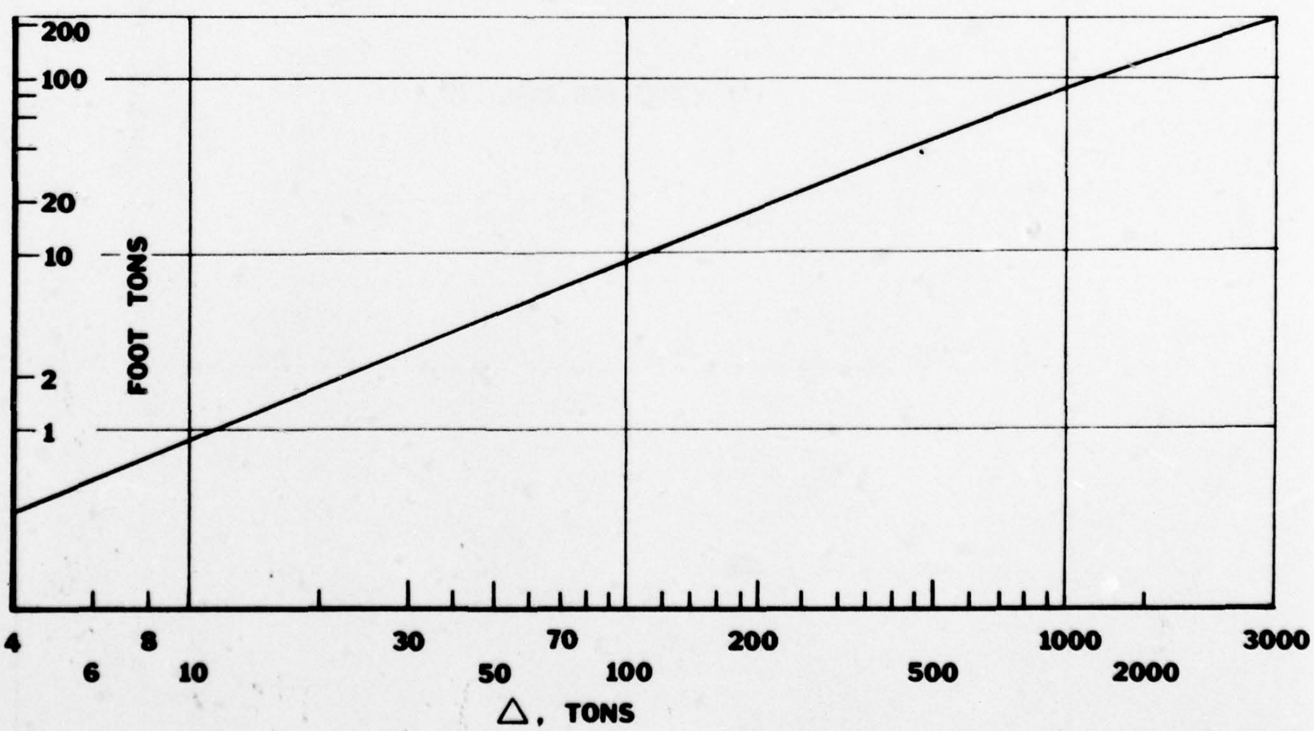


FIGURE 23

REQUIRED STABILITY
IN DAMAGED CONDITION

PART II

PROCEDURE FOR ANALYSIS

PART II - PROCEDURE FOR ANALYSIS

6.0 DATA REQUIRED FOR STABILITY ANALYSIS

6.1 INTACT STABILITY

6.1.1 BEAM WINDS COMBINED WITH ROLLING

Item	Source
Profile & Bow View of Craft	Drawing File
Cross curves of stability	Drawing File
Displacement and VCG	Weight control file
Roll angle	Sections 3.4 and 5.1.1
GM	Weight control file

6.1.2 LIFTING HEAVY WEIGHTS OVER THE SIDE

Item	Source
Location of attachment of load to boom	Rigging drawing
Amount of weight to be lifted	Operational Requirement
Cross curves	Drawing file
Displacement and VCG	Weight control file

6.1.3 CROWDING OF PASSENGERS TO ONE SIDE

Item	Source
Plan of deck areas accessible to passengers	Drawing File
Number of passengers	Operational Requirement
Cross curves	Drawing File
Displacement and VCG	Weight Control File

6.1.4 HIGH SPEED TURNING

Item	Source
Speed of craft in turn	Operational Requirement
Radius of turn	Operational Requirement
Cross curves	Drawing File
Displacement and VCG	Weight Control File

6.1.5 TOPSIDE ICING

Item	Source
Maximum expected wind velocity and/ or ice thickness in area of operation	Operational Requirement
Roll angle	Sections 3.4 and 5.1.1
Cross curves	Drawing File
Displacement and VCG	Weight Control File

6.2 DAMAGE STABILITY

Item	Source
Damaged righting arms in various conditions	Computer output
Roll angle	Section 5.2
Heel angle at which unrestricted flooding occurs	*

7.0 ANALYSIS PROCEDURE

The basic procedure is always to compare the characteristics of two curves:

- Righting Arm Curve - reflects conditions internal to the craft, CG on centerline.
- Heeling Arm Curve - reflects conditions external to the craft, and/or CG off centerline.

7.1 RIGHTING ARM CURVE

STEP 1. Determine the exact displacement for which the investigation is to be made. This may require adding weights, such as a hoisted load or ice, to the load condition reported on the weight summary sheets of the "ESTIMATE OF WEIGHT FOR BOATS". The total

*This is determined by checking the actual waterline in the damaged condition (from the damaged stability computer output) against the craft arrangement drawings.

displacement and center of gravity location may be calculated on Form 1 (See Appendix), or other suitable form.

STEP 2. Enter the craft condition, displacement and KG in the blocks provided on Form 2.

STEP 3. Enter in Column 1 each angle for which the cross curves have been plotted. If desired, for hand calculations, enter the sine of each angle in Column 2.

STEP 4. Multiply KG by the sine of each heel angle, θ, and enter in Column 3.

STEP 5. Enter the cross curves at the value of displacement found in Step 1 above, and read the value of righting arm, RA, for each heel angle. Enter these values on Form 2 in Column 4.

STEP 6. Subtract KG sin θ (Col. 3) from RA to get GZ and enter in Column 5.

STEP 7. Plot the righting arm curve (from Step 6) on Form 4.

7.2 HEELING ARM CURVES

7.2.1 WIND HEEL

STEP 1. Prepare a simplified outboard profile and end view of the craft, similar to Figure 15.

STEP 2. Block out the profile in the minimum number of rectangular planes that will represent the projected sail area.

STEP 3. Locate these planes on the end view.

STEP 4. Construct the lateral projections of these planes at a few heel angles, say 30°, 60° and 90°. For this purpose the craft can be considered to remain at constant trim, to rotate about the CG with the waterline a constant distance below the CG. For

convenience in simplifying the areas it may be desirable to trace them roughly as shown in Figure 16. Calculate these areas and enter them in Column 1 of Form 3.

STEP 5. Locate the centroid of the sail area, and the half draft point at each heel angle. (Note that the draft changes with heel angle.) Measure the vertical distance, h, between the two at each heel angle, and enter this in Column 2 of Form 3.

STEP 6. Multiply the distance, h, by the projected sail area, A, at each heel angle and enter the product in Column 3 of Form 3.

STEP 7. Calculate the wind pressure, p, in pounds per square foot, from the formula $p = 0.004 V_k^2$, for one or more wind velocities as specified. Figure 14 should be used to obtain the correct local velocity at the centroid of area, A, for the specified velocity (which is taken at a height of 10 meters).

STEP 8. Multiply the pressure, p, by the area moment in Column 3 to get the heeling moment. Enter this in Column 4.

STEP 9. Divide the values in Column 4 by the displacement of the craft to obtain heeling arms and enter these in Column 5. NOTE: The reason for separating the procedure into such a large number of steps is to facilitate additional calculations for different displacements and/or wind velocities. Any equivalent procedure may be used.

STEP 10. Plot the heeling arms on the righting arm curve, Form 4.

STEP 11. Note the angle of intersection of the two curves.

STEP 12. Lay off angle, Θ_r, as defined in Section 5.1.1.

STEP 13. Measure areas A_1 and A_2 as shown in Figure 20.

STEP 14. Divide A_1 by A_2, and note ratio.

STEP 15. Divide the heeling arm at point C by the maximum righting arm, and note ratio.

7.2.2 OFF-CENTER WEIGHT

It is assumed that a righting arm curve has been plotted for the correct displacement and vertical center of gravity, including the effects of added or swinging weights, etc., as described in Sections 2.5, 2.7, and 3.2.

STEP 1. List the amount of off-center weight, its distance off center, and the displacement in the correct places at the head of Form 5, and calculate GG' as shown.

STEP 2. Enter the desired number of heel angles in Column 1 and their cosines in Column 2. Multiply GG' by the cosine of each heel angle and enter the values in Column 3 of Form 5.

STEP 3. Plot the values from Column 3 on the righting arm curve, Form 4, for the condition under investigation.

STEP 4. Note the angle of intersection of the two curves at point C, as shown in Figure 10(A), on page 19.

STEP 5. Divide the heeling arm at point C by the maximum righting arm and note the ratio.

STEP 6. Measure the area between the curves and the total area under the righting arm curve, divide the former by the latter, and note the ratio.

7.2.3 HIGH SPEED TURNING

STEP 1. Obtain the vertical distance, a, from the half draft point to the vertical center of gravity.

STEP 2. Using the distance, a, the craft speed, υ, and the turning radius, R, calculate the heeling arm for each of several

heel angles using the formula $HA = v^2 a \cos\theta/gR$. Tabulate all calculations as shown on Form 6. ($v = 1.69\ V_k$)

STEP 3. Plot the values from Column 6 on the righting arm curve for the condition under investigation. Use Form 4.

STEP 4. Note the angle, point C, at which the heeling arm curve and righting arm curve intersect.

STEP 5. Divide the heeling arm at point C by the maximum righting arm and note the ratio.

STEP 6. Measure the area between the curves and the total area under the righting arm curve, divide the former by the latter, and note the ratio.

7.3 DAMAGE STABILITY

STEP 1. Plot the damage righting arms, as given in the computer print-out, on a copy of Form 4.

STEP 2. Plot the wind heel curve, based on the projected areas, and calculated for the specified wind velocity, on the righting arm curve.

STEP 3. Note the intersection of the two curves.

STEP 4. Measure the area between the curves, and check it against the required area from Figure 23.

REFERENCES

1. Sarchin, T. H., and Goldberg, L. L., "Stability and Buoyancy Criteria for U.S. Naval Surface Ships," SNAME 1962
2. Goldberg, L. L., and Tucker, R. G., "Current Status of U. S. Navy Stability and Buoyancy Criteria for Advanced Marine Vehicles," AIAA/SNAME Advanced Marine Vehicles Conference, San Diego 1974

EXAMPLE CALCULATION

EXAMPLE CALCULATION

The following example calculation has been prepared to clarify the procedure and illustrate one way to carry out the calculations outlined in Section 7. Other ways are possible, especially if an electronic calculator is used. Examples of two possible differences are:

- The trigonometric functions of the heel angles need not be tabulated.
- The sail area and its moment arm need not be tabulated separately.

In the process of summing the individual smaller rectangles which make up the total sail area at a given heel angle, their moments may be taken about the half draft point. The sum of these moments is Ah as given on Form 3, and this may be multiplied by p/Δ and entered directly in column (5) for the heel angle in question.

This example calculation is for a craft which approximates CPIC-X. The numbers used are not in exact agreement with any particular weight report and are not entirely consistent within themselves, but will serve well enough as an illustration.

In carrying out a stability calculation, the values for displacement, GM, etc., are found on one of the summary sheets in the Estimate of Weight for Boats, or a similar report in the weight control file. The calculation carried out on Form 1 would normally be on one of the summary sheets but is used here simply as an illustration of the summation of weights and moments. The load item shown is itself a summation of many smaller items.

After determining the new loading condition for which the stability is to be calculated, the new GM must be determined as described on Form 1 of this sample calculation. Note that the VCG shift (i.e., the KG shift) is not applied

directly to the old GM because KM changes with a change in displacement. At a particular displacement GM = KM - KG.*

The value of GM thus found is plotted at 57.3° on Form 4, as shown in the example, and a line is drawn from that point through the origin. The righting arm curve must be tangent to this line at the origin.

The work carried out on each of the sheets follows the outline in Section 7, therefore the procedure will not be repeated. If the forms and the procedure outline are studied together their use will become clear.

*** It may be convenient to use a blank copy of one of the summary sheets (pages 2, 3 or 4) as these provide blanks for the calculation of GM, trim, and other hydrostatic characteristics.**

STABILITY ANALYSIS

EXAMPLE
FORM NO. 1

WEIGHT AND C.G. CALCULATION WORK SHEET

CRAFT CPIC-X

REMARKS CRAFT IN COND. D W/ FUEL AFT

ITEM DESCRIPTION	WEIGHT	VERTICAL REF: BASELINE		LONGITUDINAL REF: ⊄, AFT = +		TRANSVERSE REF:	
	TONS	ARM	MOMENT	ARM	MOMENT	ARM	MOMENT
		1					
COND. A (LIGHT SHIP)	48.07	$\boxed{8.49}$	408.18	13.90	668.58		
LOAD DATA (FUEL AFT)	22.33	7.38	164.71	13.77	307.91		
		2					
COND D (W/ FUEL AFT)	70.40	$\boxed{8.14}$	572.89	13.86	976.49		

1 THIS NUMBER IS VCG OF BOAT BEFORE ADDITION OF WEIGHT.

2 THIS NUMBER IS VCG OF BOAT AFTER ADDITION OF WEIGHT.

NOTE: VCG = KG WHEN K IS THE REFERENCE LINE (BASELINE).

TO FIND THE NEW GM AFTER ADDITION OF WEIGHT, FIND KM FOR NEW DISP. ON CURVES OF FORM, THEN SUBTRACT THE NEW KG.

Sheet No. 1 of 6

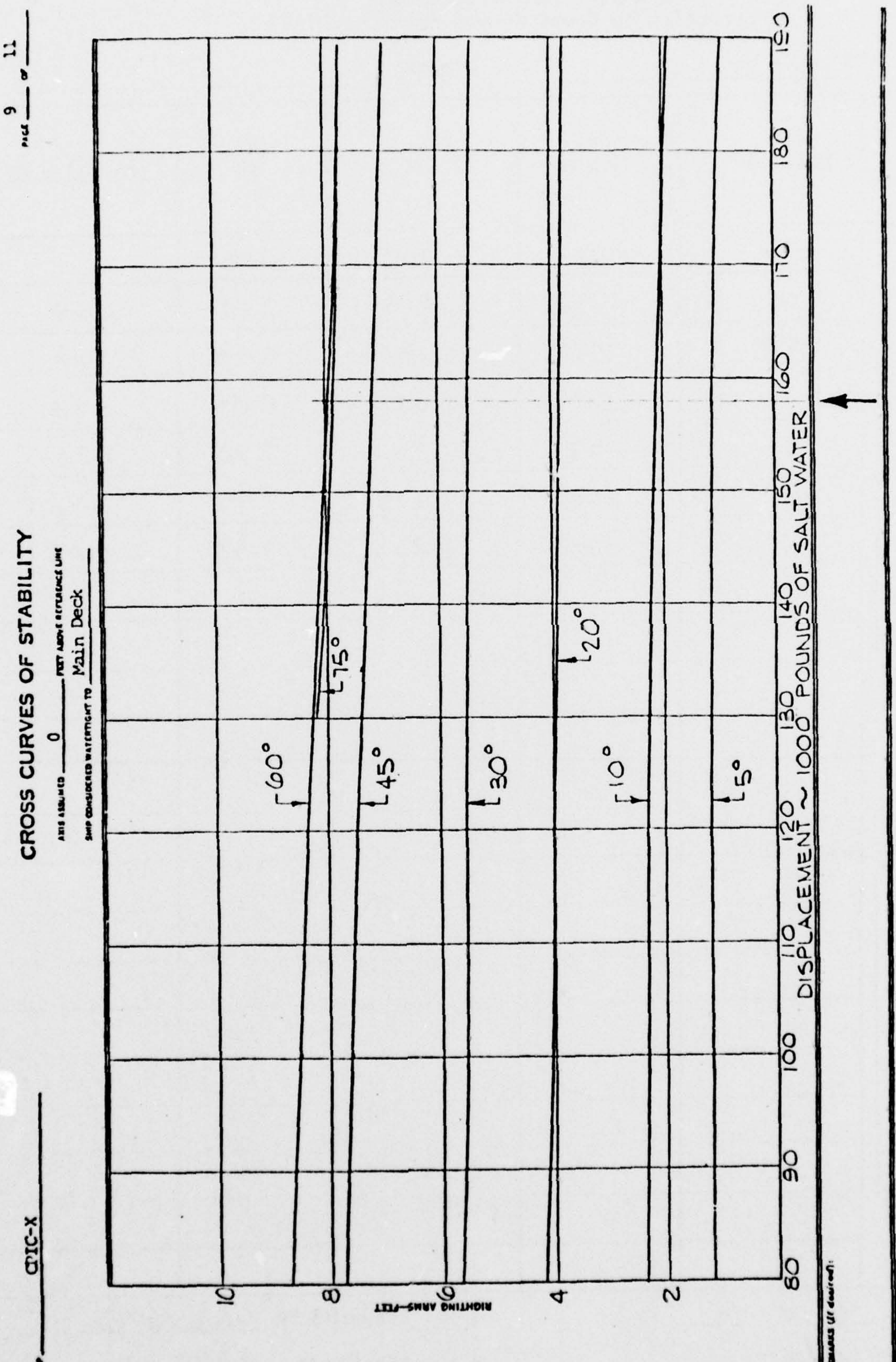
Date 1/14/77

Prepared By W. T. Hatch

Checked By C. NOBLE

EXAMPLE

BEST AVAILABLE COPY



READ RIGHTING ARMS FOR
DISP = 158,000 LB = 70.40 TONS
ENTER THEM ON FORM 2 IN COL. (4)

STABILITY ANALYSIS

EXAMPLE
FORM NO. 2

RIGHTING ARM CALCULATION
(Correction to Cross Curves for VCG shift)

CRAFT CPIC-X   REMARKS

	(1) Heel, θ	(2) Sin θ	(3) KG Sin θ	(4) RA	(5) (4)-(3) = GZ
CRAFT CONDITION D (W/FUEL AFT) DISPLACEMENT 70.40 TONS KG 8.14 FT	5	.0872	.709	1.08	.37
	10	.1736	1.413	2.10	.69
	20	.3420	2.784	3.94	1.16
	30	.5000	4.070	5.45	1.38
	45	.7071	5.756	7.12	1.36
	60	.8660	7.049	7.95	.90
	75	.9659	7.863	7.83	-0.03
CRAFT CONDITION ___ DISPLACEMENT ___ KG ___					

Sheet No. 2 of 6   Prepared By W.T. Hatch

Date 1/14/77   Checked By C. NOBLE

EXAMPLE
FORM NO. 3

STABILITY ANALYSIS

WIND HEEL CALCULATIONS

CRAFT CPIC-X REMARKS

CONDITION D (W/ FUEL AFT) DESIGN WIND SPEED 60 KT, AT 10 m.

WIND SPEED FOR CALC, V_h 48 KT, AT CENTROID OF SAIL AREA (av. 6.4' ABOVE W.L)

WIND PRESS.*; $p = 0.004\, V_h^2 = 0.004(48)^2 =$ 9.22 lb/ft^2 Δ = 158,007 lb

θ	A (1)	h (2)	Ah (3)	V_h *	p *	pAh (4)	(4):Δ (5)
0	1022	7.75	7921			73031	.462
30	1217	8.69	10576			79511	.617
60	1230	8.82	10849			100028	.633
90	1219	9.00	10969			101134	.640

CONDITION ________ DESIGN WIND SPEED ______ KT, AT 10 m.

WIND SPEED FOR CALCS, V_h _____ KT, AT CENTROID OF SAIL AREA

WIND PRESS.*; $p = 0.004\, V_h^2 = 0.004(\quad)^2 =$ _____ lb/ft^2

θ	A (1)	h (2)	Ah (3)	V_h *	p *	pAh (4)	(4):Δ (5)

*Wind pressure should be calculated separately for each heel angle if the height of the centroid of the sail area above the water surface varies more than 10% from the value at 0^0.

Sheet No. 3 of 6 Prepared by W.T. Hatch

Date 1/14/77 Checked by C. NOBLE

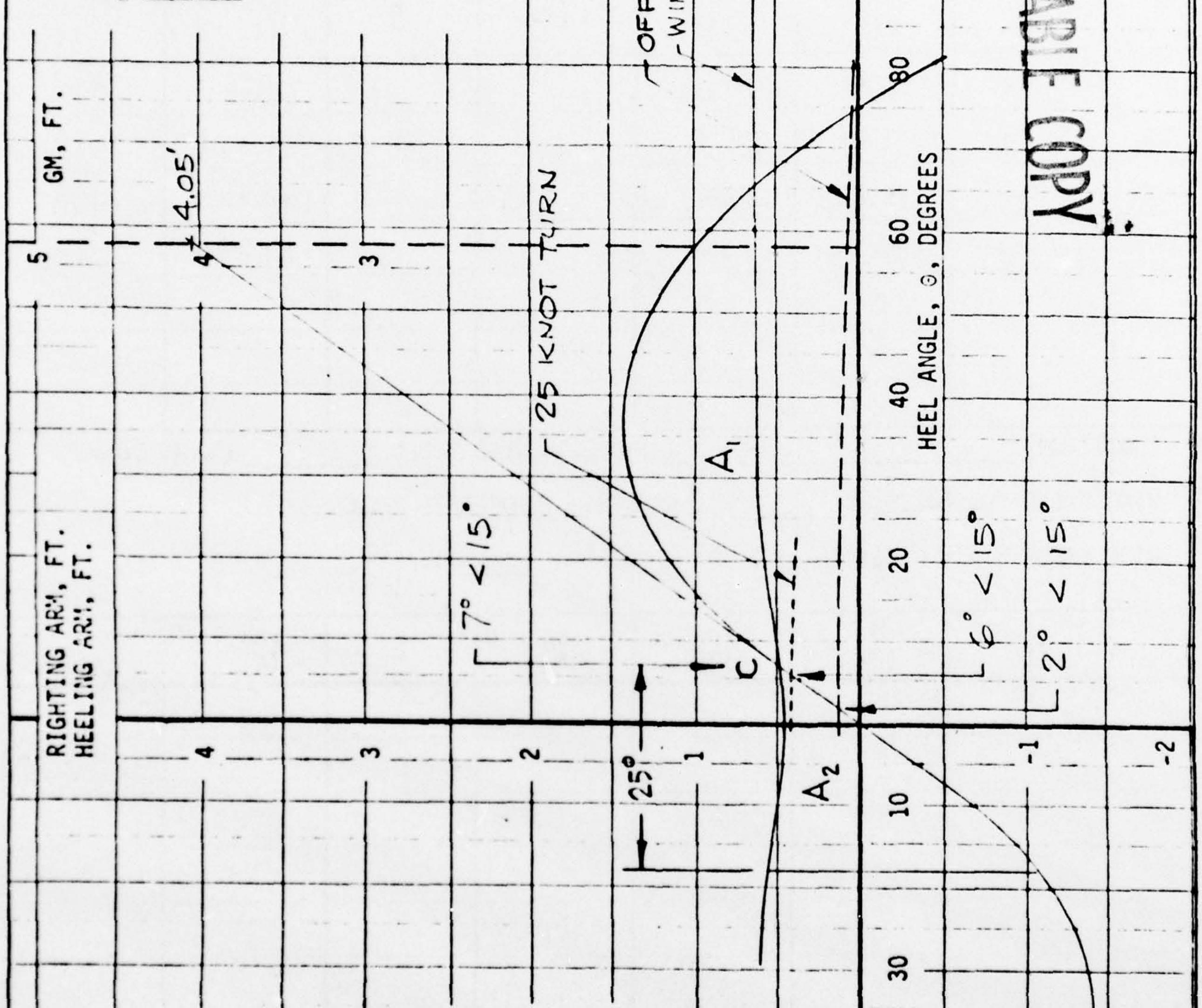
STABILITY ANALYSIS

GZ_c = 0.48 ft at 7 ° heel

GZ_{max} = 1.42 ft at 37 ° heel

$\frac{GZ_c}{GZ_{max}} = \frac{0.48}{1.42} = 0.34 < 0.6$

$\frac{\text{Area } A_1 \ 1.60 \text{ IN}^2}{\text{Area } A_2 \ 1.08 \text{ IN}^2} = 1.48 > 1.40$



STABILITY CURVES

CRAFT CPIC-X DISPLACEMENT 70.40 TONS = 158,000 LB

CONDITION D (w/FUEL AFT). GM 4.05 FT

Sheet No. 4 of 6

Date 1/14/77

Prepared by W.T. H.

Checked by C. NOELC

EXAMPLE
FORM NO. 5

STABILITY ANALYSIS

CALCULATION FOR OFF-CENTER LOAD

CRAFT CPIC-X REMARKS SHIPS COMPLEMENT = 13 MEN

Lateral shift of CG of craft, $GG' = W\ell / \Delta$ 13 MEN × 165 LB/MAN = 2145 LB

Heeling arm, $HA = GG'\cos\Theta$

LOAD CONDITION D (W/FUEL AFT)

OFF CENTER WEIGHT, W = 2145 lb

DIST. OFF CENTER, ℓ = 9 ft

DISPLACEMENT, Δ = 158,000 lb

$GG' = \frac{W\ 2145 \times \ell\ 9.0}{\Delta\ 158\ 000} = 0.122$ ft

LOAD CONDITION ______

OFF CENTER WEIGHT, W = ______ lb

DIST OFF CENTER, ℓ = ______ ft

DISPLACEMENT, Δ = ______ lb

$GG' = \frac{W \times \ell}{\Delta}$ = ______ ft

(1) Θ	(2) $\cos\Theta$	(3) HA	(1) Θ	(2) $\cos\Theta$	(3) HA
0	1.000	.122			
20	.940	.115			
40	.766	.094			
60	.500	.061			
80	.174	.021			

Sheet No. 5 of 6
Date 1/14/77

Prepared by W. T. Hatch
Checked by C. NOBLE

STABILITY ANALYSIS

EXAMPLE
FORM NO. 6

CALCULATION FOR HIGH SPEED TURN

CRAFT CPIC-X

CONDITION D (W/ FUEL AFT)

$HA = \frac{v^2 a \cos \theta}{gR}$

Displacement 158,000 lb

v = speed of craft in turn, fps

VCG 8.14 - 6.0 = 2.14 ABOVE W.L. Draft (Hull) 3.3 FT

g = 32.2 ft/sec^2

R = turning radius, ft.

θ = heel angle

a = dist of VCG above half-draft, 2.14 + 1.65 = 3.79 ft.

(1) v in turn fps	(2) R * ft	(3) $\frac{v^2a}{gR}$	(4) heel θ degrees	(5) cos θ	(6) heeling arm (3) x (5)
25 x 1.69 42.25	500	.420	0	1.000	.420
			10	.985	.414
			20	.940	.395
35 59.15	1000	.412	0	1.000	.412
			10	.985	.406
			20	.940	.387

Sheet No. 6 of 6

Date 1/14/77

Prepared by W. F. Haick

Checked by C. NOBLE

* THESE ARE HYPOTHETICAL FIGURES.

APPENDIX

STANDARD FORMS

WEIGHT AND C.G. CALCULATION WORK SHEET

CRAFT ____________________ REMARKS ____________________

ITEM DESCRIPTION	WEIGHT	VERTICAL REF: BASELINE		LONGITUDINAL REF:		TRANSVERSE REF:	
		ARM	MOMENT	ARM	MOMENT	ARM	MOMENT

Sheet No. ____ of ____ Prepared By ____________

Date ____________ Checked By ____________

STABILITY ANALYSIS FORM NO. 2

RIGHTING ARM CALCULATION
(Correction to Cross Curves for VCG shift)

CRAFT ______________________ REMARKS ______________________

	(1) Heel, θ	(2) Sin θ	(3) KG Sin θ	(4) RA	(5) (4)-(3) = GZ
CRAFT CONDITION ______ DISPLACEMENT ______ KG ______					
CRAFT CONDITION ______ DISPLACEMENT ______ KG ______					

Sheet No. _____ of ______ Prepared By ________________

Date ________________ Checked By ________________

STABILITY ANALYSIS

FORM NO. 3

WIND HEEL CALCULATIONS

CRAFT ______________________ REMARKS ______________________

CONDITION ______________________ DESIGN WIND SPEED __________ KT, AT 10 m.

WIND SPEED FOR CALC, V_h ______ KT, AT CENTROID OF SAIL AREA

WIND PRESS.*; $p = 0.004\ V_h^2 = 0.004(\quad)^2 =$ ______ lb/ft^2

θ	A (1)	h (2)	Ah (3)	V_h *	p *	pAh (4)	(4)÷Δ (5)

CONDITION ______________________ DESIGN WIND SPEED __________ KT, AT 10 m.

WIND SPEED FOR CALCS, V_h ______ KT, AT CENTROID OF SAIL AREA

WIND PRESS.*; $p = 0.004\ V_h^2 = 0.004(\quad)^2 =$ ______ lb/ft^2

θ	A (1)	h (2)	Ah (3)	V_h *	p *	pAh (4)	(4)÷Δ (5)

*Wind pressure should be calculated separately for each heel angle if the height of the centroid of the sail area above the water surface varies more than 10% from the value at 0^0.

Sheet No. _____ of _____ Prepared by ______________________

Date ______________________ Checked by ______________________

STABILITY ANALYSIS

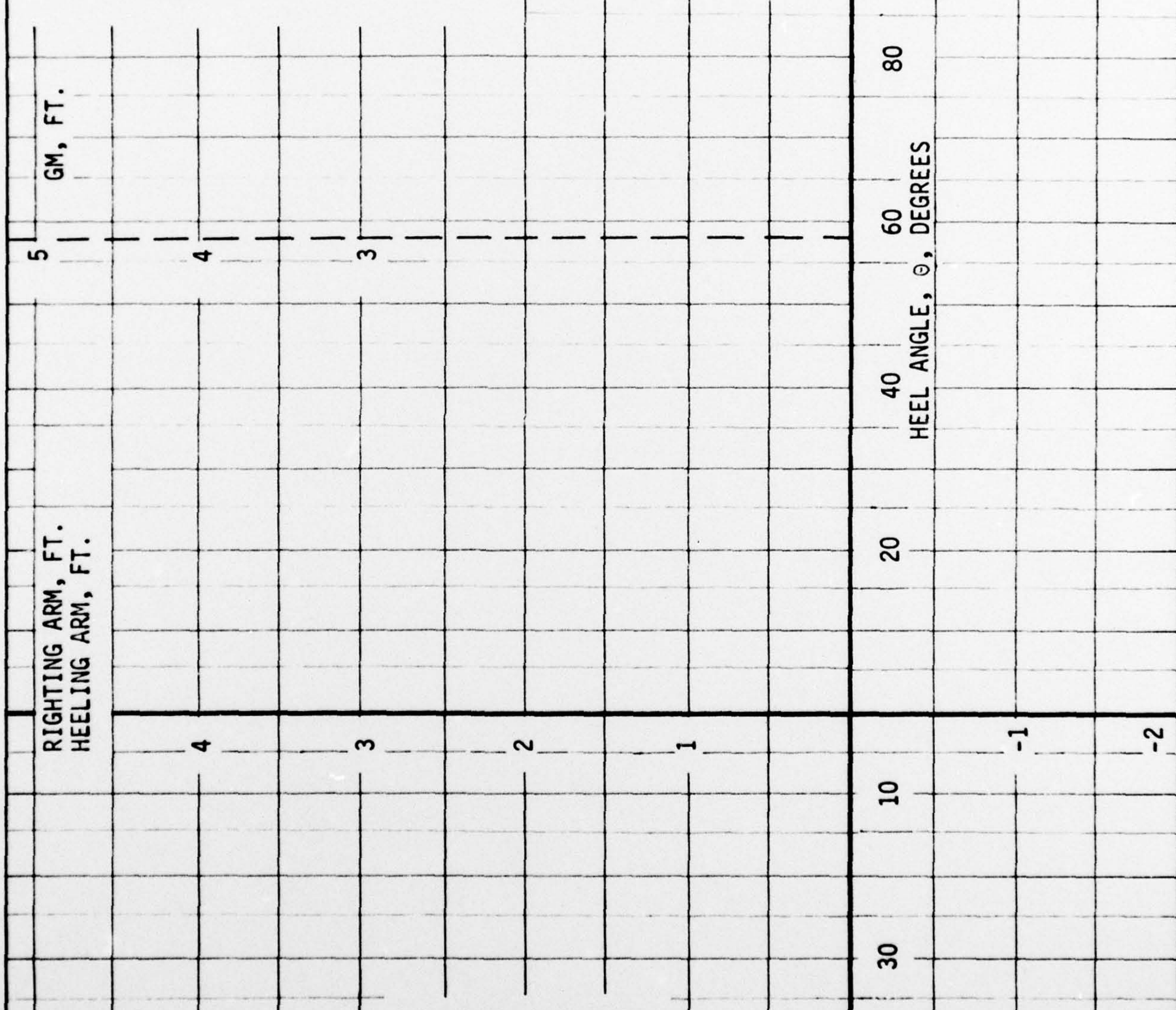
FORM NO. 4

GZ_c = _____ ft at _____ ^{o} heel

GZ_{max} = _____ ft at _____ ^{o} heel

$\frac{GZ_c}{GZ_{max}}$ = _______

$\frac{\text{Area } A_1 \text{ \_\_\_\_\_\_}}{\text{Area } A_2 \text{ \_\_\_\_\_\_}}$ = _______



STABILITY CURVES

CRAFT ______________ DISPLACEMENT __________

CONDITION __________________ GM __________

Sheet No. _____ of _____

Prepared by ________________

Date __________________

Checked by ________________

CALCULATION FOR OFF-CENTER LOAD

CRAFT ______________________ REMARKS ______________________

Lateral shift of CG of craft, $GG' = W\ell / \Delta$

Heeling arm, $HA = GG'\cos\Theta$

LOAD CONDITION ______________	LOAD CONDITION ______________
OFF CENTER WEIGHT, W = __________ lb	OFF CENTER WEIGHT, W = __________ lb
DIST. OFF CENTER, ℓ = __________ ft	DIST OFF CENTER, ℓ = __________ ft
DISPLACEMENT, Δ = __________ lb	DISPLACEMENT, Δ = __________ lb
$GG' = \dfrac{W \_\_\_\_ \times \ell \_\_\_\_}{\Delta \_\_\_\_}$ = __________ ft	$GG' = \dfrac{W \_\_\_\_ \times \ell \_\_\_\_}{\Delta \_\_\_\_}$ = __________ ft

(1) Θ	(2) cos Θ	(3) HA	(1) Θ	(2) cos Θ	(3) HA

Sheet No. _____ of _____ Prepared by ______________

Date ______________ Checked by ______________

CALCULATION FOR HIGH SPEED TURN

CRAFT ______________________ CONDITION ______________________

$HA = \frac{v^2 a \cos \theta}{gR}$

Displacement ______________________

v = speed of craft in turn, fps

VCG ____________ Draft ____________

g = 32.2 ft/sec^2

R = turning radius, ft.

θ = heel angle

a = dist of VCG above half-draft, _____ ft.

(1) v in turn fps	(2) R ft	(3) $\frac{v^2 a}{gR}$	(4) heel θ degrees	(5) $\cos \theta$	(6) heeling arm (3) x (5)

Sheet No. _____ of _____ Prepared by ______________________

Date ______________________ Checked by ______________________

ESTIMATE OF WEIGHT FOR BOATS WORK SHEET

NAVSHIPS-4616.1 (REV. 11-57)

U.S.S. ____________________

BUDGET BUREAU NO. 45-R281
REPORT-BUSHIPS-9291-4

PAGE ______ OF ______

DATE

DESCRIPTION	WEIGHT (Pounds)	CENTER OF GRAVITY					
		ABOVE BASE	MOMENTS	REFERRED TO FRAME NO.			
				FWD	MOMENTS	AFT	MOMENTS

ESTIMATED BY

CHECKED BY

ESTIMATE OF WEIGHT FOR BOATS
BOAT IN LIGHT CONDITION - PAGE 1
NAVSHIPS 4610.2 (REV. 11-57)

U.S.S. ____________________

BUDGET BUREAU NO. 45-R281
REPORT-BUSHIPS-9291-4

PAGE 1 OF ______

DATE

GROUP	DESCRIPTION	WEIGHT (Pounds)	CENTER OF GRAVITY					
			ABOVE BASE	MOMENTS	REFERRED TO FRAME NO			
					FWD	MOMENTS	AFT	MOMENTS
1	HULL STRUCTURE							
2	PROPULSION							
3	ELECTRIC PLANT							
4	COMMUNICATION AND CONTROL							
5	AUXILIARY SYSTEMS							
6	OUTFIT AND FURNISHINGS							
7	ARMAMENT							
	STOWAGE							
	MARGIN							
	BOAT IN LIGHT CONDITION							
	BASE ABOVE/BELOW BOTTOM OF KEEL - FEET							
	CENTER OF GRAVITY ABOVE BOTTOM OF KEEL - FEET							

LIGHT CONDITION

Boat complete, ready for service in every respect, but without ammunition, stores, fresh water, complement, fuel or any other items of consumable or variable load. Includes liquids in machinery and systems at operating levels.

DRAFT CORRESPONDING TO ABOVE DISPLACEMENT AT CENTER OF FLOTATION	FEET
TRANSVERSE METACENTER ABOVE ______ AT ABOVE MEAN DRAFT	FEET
C.G. ABOVE ______	FEET
GM	FEET
MOMENT TO ALTER TRIM 1 INCH	FT. POUNDS
C.B. OF BOAT ON EVEN KEEL AT ABOVE DRAFT FORWARD/AFT OF REFERENCE FRAME	FEET
C.G. FORWARD/AFT OF REFERENCE FRAME	FEET
TRIMMING LEVER FORWARD/AFT	FEET
$\text{TRIM} = \dfrac{\text{DISP'T } (pounds) \times \text{TRIMMING LEVER } (ft.)}{\text{MOMENT TO ALTER TRIM 1 IN. } (ft.\ pounds)} =$ ______ =	INCHES BY HEAD/STERN
$\text{DIFF. IN DRAFT BETWEEN L.C.F. AND MIDSHIPS} = \dfrac{\text{TRIM} \times \text{CG OF WP AFT OF WP } (ft.)}{\text{L.B.P. } (ft.)} =$ ______ =	FEET INCREASE/DECREASE
$\text{LIST} = \dfrac{\text{HEELING MOMENT } (ft.\ pounds)}{.01745 \times \text{DISP'T } (pounds) \times \text{GM}} =$ ______ =	DEGREES PORT/STARBOARD
DRAFTS ABOVE ______ AT PERPENDICULARS FORWARD FT.	INCHES
AFT FT.	INCHES
MEAN FT.	INCHES

COMPUTING BY	COMPUTING CHECKED

ESTIMATE OF WEIGHT FOR BOATS
BOAT IN HOISTING CONDITION - PAGE 2
NAVSHIPS 4616-2 (REV. 11-57)

U.S.S. ______

BUDGET BUREAU NO. 45-R281
REPORT-BUSHIPS-9291-4

DATE

DESCRIPTION	WEIGHT (Pounds)	CENTER OF GRAVITY: ABOVE BASE	MOMENTS	REFERRED TO FRAME NO.: FWD	MOMENTS	AFT	MOMENTS
BOAT IN LIGHT CONDITION *(From Page 1)*							
AMMUNITION							
STORES							
POTABLE WATER							
FUEL							
CARGO							
COMPLEMENT							
SLINGS							
BOAT IN HOISTING CONDITION							
BASE ABOVE/BELOW BOTTOM OF KEEL - FEET							
CENTER OF GRAVITY ABOVE BOTTOM OF KEEL - FEET							

HOISTING CONDITION

This condition is defined in the detail specifications.

DRAFT CORRESPONDING TO ABOVE DISPLACEMENT AT CENTER OF FLOTATION	FEET
TRANSVERSE METACENTER ABOVE ______ AT ABOVE MEAN DRAFT	FEET
C.G. ABOVE ______	FEET
GM NO CORRECTION FOR FREE SURFACE. FEET (CORRECTION = *feet*). GM. CORRECTED FOR FREE SURFACE.	FEET
MOMENT TO ALTER TRIM 1 INCH	FT. POUNDS
C.B. OF BOAT ON EVEN KEEL AT ABOVE DRAFT FORWARD/AFT OF REFERENCE FRAME	FEET
C.G. FORWARD/AFT OF REFERENCE FRAME	FEET
TRIMMING LEVER FORWARD/AFT	FEET
TRIM = $\frac{\text{DISP'T (pounds) x TRIMMING LEVER (ft.)}}{\text{MOMENT TO ALTER TRIM 1 IN. (ft. pounds)}}$ = ______ =	INCHES BY HEAD/STERN
DIFF. IN DRAFT BETWEEN L.C.F. AND MIDSHIPS = $\frac{\text{TRIM x CG OF WP AFT OF MP (ft.)}}{\text{L.B.P. (ft.)}}$ = ______ =	FEET INCREASE/DECREASE
LIST = $\frac{\text{HEELING MOMENT (ft. pounds)}}{\text{.01745 x DISP'T (pounds) x GM}}$ = ______ =	DEGREES PORT/STARBOARD
DRAFTS ABOVE ______ AT PERPENDICULARS FORWARD FT.	INCHES
AFT FT.	INCHES
MEAN FT.	INCHES

COMPUTING BY	COMPUTING CHECKED

ESTIMATE OF WEIGHT FOR BOATS

BOAT IN TRIAL CONDITION - PAGE 3
NAVSHIPS 4616-2 (REV. 11-57)

U.S.S. ______________

BUDGET BUREAU 45-R281
REPORT-BUSHIPS-9291-4

PAGE 3 OF ______

DATE

DESCRIPTION	WEIGHT (*Pounds*)	CENTER OF GRAVITY: ABOVE BASE	MOMENTS	REFERRED TO FRAME NO: FWD	MOMENTS	AFT	MOMENTS
BOAT IN LIGHT CONDITION (*From Page 1*)							
AMMUNITION							
STORES							
POTABLE WATER							
FUEL							
CARGO							
COMPLEMENT							
BOAT IN TRIAL CONDITION							
BASE ABOVE/BELOW BOTTOM OF KEEL - FEET							
CENTER OF GRAVITY ABOVE BOTTOM OF KEEL - FEET							

TRIAL CONDITION		
This condition is defined in the detail specifications.	DRAFT CORRESPONDING TO ABOVE DISPLACEMENT AT CENTER OF FLOTATION	FEET
	TRANSVERSE METACENTER ABOVE ______ AT ABOVE MEAN DRAFT	FEET
	C.G. ABOVE ______	FEET
	GM NO CORRECTION FOR FREE SURFACE. FEET (CORRECTION = *feet*). GM, CORRECTED FOR FREE SURFACE.	FEET
	MOMENT TO ALTER TRIM 1 INCH	FT. POUNDS
	C.B. OF BOAT ON EVEN KEEL AT ABOVE DRAFT FORWARD/AFT OF REFERENCE FRAME	FEET
	C.G. FORWARD/AFT OF REFERENCE FRAME	FEET
	TRIMMING LEVER FORWARD/AFT	FEET
	TRIM = $\frac{\text{DISP'T (pounds) x TRIMMING LEVER (ft.)}}{\text{MOMENT TO ALTER TRIM 1 IN. (ft. pounds)}}$ = ______ =	INCHES BY HEAD/STERN
	DIFF. IN DRAFT BETWEEN L.C.F. AND MIDSHIPS = $\frac{\text{TRIM x CG OF WP AFT OF MP (ft.)}}{\text{L.B.P. (ft.)}}$ = ______ =	FEET INCREASE/DECREASE
	LIST = $\frac{\text{HEELING MOMENT (ft. pounds)}}{\text{.01745 x DISP'T (pounds) x GM}}$ = ______ =	DEGREES PORT/STARBOARD
	DRAFTS ABOVE ______ AT PERPENDICULARS FORWARD FT.	INCHES
	AFT FT.	INCHES
	MEAN FT.	INCHES
	COMPUTING BY	COMPUTING CHECKED

ESTIMATE OF WEIGHT FOR BOATS
BOAT IN FULL LOAD CONDITION - PAGE 4
NAVSHIPS 4616-2 (REV. 11-57)

U.S.S. ______

BUDGET BUREAU 45-R281
REPORT-BUSHIPS-9291-4

PAGE 4 OF ______
DATE

DESCRIPTION	WEIGHT (*Pounds*)	CENTER OF GRAVITY ABOVE BASE	MOMENTS	REFERRED TO FRAME NO. FWD	MOMENTS	AFT	MOMENTS
BOAT IN LIGHT CONDITION (*From Page 1*)							
AMMUNITION							
STORES							
POTABLE WATER							
FUEL							
CARGO							
COMPLEMENT							
BOAT IN FULL LOAD CONDITION							
BASE ABOVE/BELOW BOTTOM OF KEEL - FEET							
CENTER OF GRAVITY ABOVE BOTTOM OF KEEL - FEET							

FULL LOAD CONDITION

Boat complete, ready for service in every respect; officers and men and their effects; standard allowance plus mobilization supply of ammunition; full supply of consumable stores for period specified in the design characteristics; all equipment, spare parts, tools and maintenance supplies; potable water (full tanks); fuel (full tanks); full cargo, whether liquid or solid, plus passengers.

DRAFT CORRESPONDING TO ABOVE DISPLACEMENT AT CENTER OF FLOTATION ______ FEET

TRANSVERSE METACENTER ABOVE ______ AT ABOVE MEAN DRAFT ______ FEET

C.G. ABOVE ______ FEET

GM NO CORRECTION FOR FREE SURFACE. ______ FEET (CORRECTION = ______ *feet*). GM CORRECTED FOR FREE SURFACE. ______ FEET

MOMENT TO ALTER TRIM 1 INCH ______ FT. POUNDS

C.B. OF BOAT ON EVEN KEEL AT ABOVE DRAFT FORWARD/AFT OF REFERENCE FRAME ______ FEET

C.G. FORWARD/AFT OF REFERENCE FRAME ______ FEET

TRIMMING LEVER FORWARD/AFT ______ FEET

TRIM = $\frac{\text{DISP'T } (pounds) \times \text{TRIMMING LEVER } (ft.)}{\text{MOMENT TO ALTER TRIM 1 IN. } (ft.\ pounds)}$ = ______ = ______ INCHES BY HEAD/STERN

DIFF. IN DRAFT BETWEEN L.C.F. AND MIDSHIPS = $\frac{\text{TRIM} \times \text{CG OF WP AFT OF MP } (ft.)}{\text{L.B.P. } (ft.)}$ = ______ = ______ FEET INCREASE/DECREASE

LIST = $\frac{\text{HEELING MOMENT } (ft.\ pounds)}{.01745 \times \text{DISP'T } (pounds) \times \text{GM}}$ = ______ = ______ DEGREES PORT/STARBOARD

DRAFTS ABOVE ______ AT PERPENDICULARS FORWARD ______ FT. ______ INCHES

AFT ______ FT. ______ INCHES

MEAN ______ FT. ______ INCHES

COMPUTING BY ______ COMPUTING CHECKED ______

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